APPLICATION OF 3S TECHNOLOGY IN DISASTER RISK RESEARCH IN THE NORTHERN MOUNTAINOUS REGION OF VIETNAM

***Dieu Trinh NGUYEN*[1], *Quoc Lap KIEU*[2*]**

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ABSTRACT:

The article presents an overview of 3S technology application studies and prospects for 3S technology application in disaster risk management in the northern mountainous region of Vietnam. The study uses the document review method and builds an experimental research model by GIS spatial analysis method, data mining method from satellite images, combined with positioning equipment. 3S technology shows great promise in disaster management, assessment and warning in mountainous areas, especially the online warning model based on artificial intelligence and smart applications on mobile phones. This is a research direction with high practicality, accuracy and applicability. Experimental research model applying 3S technology to build landslide risk map in Lai Chau province has identified 753.62 km^2 (accounting for 8.31%) with very high landslide risk and 1633.29 km^2 (accounting for 18 01%) have a high risk of landslides. In areas with high and very high risk of landslides, the study tested the installation of online landslide warning devices, which help prevent and mitigate damage caused by landslides.

Key-words:*3S technology, disaster risk, landslides, mountainous region, Vietnam*

1. INTRODUCTION

The mountainous area in the North of Vietnam has diverse natural conditions, high mountainous terrain, complex climate, and rich mineral resources. However, this is an area where natural disasters often occur, causing great damage to people and properties. According to statistics in 20 years (2001-2021) in the northern mountainous provinces of Vietnam, there have been 318 flash floods, 3537 landslides, 128 hail storms, 604 storms, making 1486 people dead, 3512 injured, 17129 houses destroyed, property and crop damage estimated at over $4.3 billion (Statistical Office of Vietnam, 2022). The northern mountainous region of Vietnam is home to mainly ethnic minorities, with very limited skills in responding to natural disasters. Local authorities have not yet taken practical measures to forecast and warn of natural disaster risks. Natural disaster risks often occur quickly, with great consequences, and are often concentrated in remote, isolated and ethnic minority areas. Research and application of new technologies for disaster risk management in mountainous areas of Vietnam are still limited.

3S technology is a geospatial technology, combining 3 components: Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS). RS technology provides satellite image data to analyze the factors of climate, topography, geomorphology, soil, flow, vegetation these are the factors that form disaster risk. GIS supports spatial analysis, the establishment of warning maps, and disaster risk forecasting. GPS allows locating sensor devices, serving online forecasting and warning on mobile devices. Nowadays, the application of 3S technology in disaster risk management research is very popular. 3S technology is often applied in spatial analysis, establishment of disaster risk zoning maps, analysis of factors that arise and types of disaster risk, management and prediction of disaster risks (Albano et al., 2018).

[1]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi 100000, Vietnam, nguyendieutrinh70@gmail.com*

[2,*]*Thai Nguyen University of Sciences, Thai Nguyen 250000, Vietnam, lapkq@tnus.edu.vn*

Current trending disaster risk susceptibility assessment focuses on the use of machine learning, spatial statistics, and multi-criteria decision-making algorithms. The directions for studying the susceptibility to disaster risks are provided by machine learning models such as logistic regression laws (Ali et al., 2020), decision trees (Khosravi et al., 2019; Zhao et al., 2019), artificial neural networks (Chapi et al., 2017; Choubin et al., 2017; Costache et al., 2019; Bui, 2020), support vectors (Tehrany et al., 2014), neural fuzzy inference systems (Wang et al., 2019). Bilateral statistical models, including studies involving: frequency ratio (Shafapour et al., 2019), weight of evidence (Rahmati et al., 2016), statistical index, the coefficient of certainty (Costache et al., 2019) and the entropy index (Azareh et al., 2019). For multi-criteria decision making, commonly used analytical hierarchical techniques (Souissi et al., 2019), multi-criteria optimization (Dano et al., 2019) and sorting techniques are commonly used. order of preference according to the similarity to the ideal solution (Kim et al., 2020). Method of applying K-Star model to determine and calculate disaster risk potential index (Der et al., 2019; Uddin et al., 2021).

The application of 3S technology brings many advantages in spatial analysis, creating disaster risk warning partition maps (Cao, 2016; Albano, 2018; Der Sarkissian et al., 2019; Popa, 2019; Yi, 2021). Studies regarding based on remote sensing and GIS mainly use the FFPI model to create disaster risk warning maps (Gregory, 2010; Ballesteros et al., 2017; Costache et al, 2019). Studies used the data of slopes, soil types, soil utilization types and vegetation cover to build a potential map, which provided excellent support for disaster risk forecasting activities (Bajabaa, 2014; Roxana, 2018).Proposed the physically based, space-time distributed hydrological model and the geomorphological instantaneous unit hydrograph has been derived from the geomorphological characteristics of a catchment and used in simulation of the surface runoff hydrographs for ten rainfall events in the Ajay Catchment in eastern India (Estupina-Borrell et al., 2006; Kumar et al., 2007). Growing knowledge of disaster riskmechanisms shows that the morphometric variables of a catchment control its hydrological response (Moussa, 2003). Based on this understanding, the geomorphological unit hydrograph has become one of the most popular methods for estimating hydrological processes when data are inadequate (Du et al., 2009; Diakakis, 2011).

Research into the application of opensource software, webGIS, and artificial intelligence in disaster risk management is also becoming more and more popular. The case studies were promoting spatial thinking through local disaster risk management planning (Berse et al., 2011, Kieu, 2021), application of WebGIS technology in disaster risk management support (Kawasaki et al., 2012), disaster risk reduction in agriculture through Big data processing (Reznik et al., 2017), potential disaster risk zonation and flood shelter suitability mapping for disaster risk mitigation using artificial intelligence (Uddin et al., 2021).

In recent years 3S technology has been applied in disaster risk management research in Vietnam. However, the research is in the initial application form, the database and research methods are still limited. This study will present an overview of the application of 3S technology in Vietnam and new prospects for the application of 3S technology in disaster risk management in the northern mountainous region of Vietnam. Experimental study to establish landslide map and landslide warning model in Lai Chau province as an illustrative example. This is the first study on the application of 3S technology in landslide warning in Lai Chau province, especially the online warning model. The research results have shown the prospect of applying 3S technology in research and management of different types of disaster risks in Vietnam.

2. STUDY AREA

The northern mountainous region of Vietnam has a total area of 100,965 km², with a population of about 14.62 million, which are mainly ethnic minorities (Statistical Office of Vietnam, 2022). Administratively, this region 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 and Quang Ninh). This is an area with diverse and complex natural conditions, into two sub-regions Northwest and Northeast. The Northwest is an area consisting mainly of medium and high mountains. This is the place with the highest, divided and most dangerous terrain in Vietnam.

The average slope is 23.7 degrees, many areas have slopes above 30 degrees. The common terrain types here are high mountains, deep valleys or canyons, limestone plateaus with an average altitude of 800-1000m. The highest and most massive mountain range is Hoang Lien Son range with many peaks over 2500m, the highest peak is Fansipan 3143m high. The Northeast mountainous region consists mainly of medium and low mountains. The massif upstream of Chay river has many peaks above and below 2000m, which is the highest area of the region. From this massif to the sea are bow-shaped mountain ranges that gradually lower towards the East Sea.

The river and stream system in the northern mountainous region of Vietnam is quite dense, with an average density of about 1.45km/km^2, with the Red river, Da river and Chay river being the main hydrological systems. The tropical monsoon climate of the high mountains has cold winters, the average annual temperature ranges from 18-25^{0}C, the average annual rainfall is 1800 mm (Vietnam's Ministry of Natural Resources and Environment, 2020). Due to the high mountainous terrain and distinct seasonality, the climate is clearly differentiated, with many areas having extreme climates, with extreme cold in winter and heavy rainfall in summer. Forest coverage in the area reaches 46.28%, unevenly distributed, mainly planted forest area. The area of natural forests and protection forests accounts for only 5.1% of the natural area. Meanwhile, the area of bare land and bare hills tends to increase. Data from satellite image analysis in December 2020 shows that bare land and bare hills account for 23.7% of the area's natural area (Kieu, 2021). Soil in the mountainous area is quite rich, with nearly 30 main soil groups, of which the most are red-yellow ferralit soils, black soils, red humus soils, alite humus in the mountains, coarse humus in the mountains, and soil. Yellow-red soil is changed by rice cultivation, strongly eroded soil inert with gravel, alluvial soil, and sloping soil (Vietnam's Ministry of Natural Resources and Environment, 2020).

The northern mountainous region of Vietnam is an area that frequently experiences natural disaster risks and suffers heavy losses due to major types of natural disasters such as flash floods, landslides, cold weather, hoarfrost, drought, storm, ice, snow, etc. The provinces most affected are Lai Chau province, Yen Bai province, Lao Cai province and Son La province. This is the main distribution area of ethnic minorities, and disaster risk prevention skills are still limited. Agricultural farming activities are backward, mainly cultivating crops (maize, cassava, upland rice, medicinal plants,...) in the uplands, growing wet rice in the valleys, farming by terraced fields, and exploiting forest products. Economic activities depend on nature, which makes the risk of natural disasters and damage from disaster risks tend to increase (Vietnam's Disaster Prevention and Control Office, 2021).

3. DATA AND METHODS

3.1. Study data

To analyze the prospects of 3S technology application in disaster risk management and forecasting, the study has reviewed many different data sources. The author has reviewed more than 300 studies related to the application of geospatial technology in disaster risk management, including 50 basic studies on 3S technology application in analysis, assessment and management natural disaster risks in mountainous areas. In Vietnam, all relevant studies are collected, including reporting data, statistics on the current state of disaster risk in mountainous areas in the last 20 years, research data on types of natural disaster risks; and especially studies with application of satellite images, GIS and GPS in disaster risk management are collected and analyzed.

In an empirical research model, an applied case study of landslides in Lai Chau province, the study used survey data, statistical data, data observations, satellite images, paper maps and data from landslide-related studies in Lai Chau province. Topographic data is inherited, extracted from the topographic map of Lai Chau province, scale 1:200,000. Slope data, terrain segmentations are built on digital elevation model (DEM) and satellite image data. The petrographic map is built according to the principle of morphological origin, combining data from geological maps.

Soil type data was surveyed by the author and inherited from the analysis results of 100 soil profiles, representing 18 soil types covering the entire study area. Data on land use status based on Sentinal-2B satellite image, Landsat 8 ETM image (Earthexplorer.usgs.gov, 2022) and field inspection data. Rainfall data are collected from the rainfall database of the National Institute of Meteorology, Hydrology and Climate Change over a period of over 60 years (1960-2021), combining rainfall monitoring data of 35 IMETOS monitoring stations located in the study area. The data on the current state of landslides (location, extent, extent of influence, time) for 20 years (2001-2021) are used from statistical documents, combined with survey and interview methods. people in the study area.

3.2. Study methods

Review of related studies to analyze the prospects of 3S technology in disaster risk management in the northern mountainous region of Vietnam. The main method is to collect, analyze and synthesize documents; The study evaluates the overview based on the analysis of previous research results. Using the method of collecting and processing statistical data, using remote sensing image data to collect data related to natural features, current state of landslides, factors affecting landslides in the experimental area. The field survey method conducts a survey of sample study sites to verify statistical data and verify analysis results. At the same time, through the survey process, to locate and identify the locations of natural disasters in the study area.

In the experimental research model, the hierarchical analysis method is applied, combined with the spatial analysis method in GIS to build a landslide hazard map. The method of hierarchical analysis (Saaty, 1987) is applied to calculate the consistency index, determine the randomness index, the weight of each factor causing landslides in the experimental area. Employing Multi-Criteria Analysis technique (Triantaphyllou, 2000), this study focused on the determination of factors that formed landslides in the research area and simultaneously combined the goal with statistical data for comparisons, ultimately leading to the hierarchy of the capability to cause landslides of information layers. With the application of GIS in determining weights, the spatial integration of factors and weights in order to build a map of landslides potentials in the study area.

The sensitivity level reflecting landslide risk is calculated according to the formula (1):

$$\mathrm{LSI} = \sum_{j=1}^{n} \mathrm{Wj}\,.\mathrm{Xij} \quad (1)$$

where: *LSI is landslide susceptibility index*

W_j is the weight of factor (j)

X_{ij} is landslide factor (j) in layer (i)

n is the number of factors causing landslides.

In the experimental model, 6 factors that cause landslides including slope, daily rainfall, soil type, current land use status, geological background and topographic dissection.

GIS enables spatial analysis, management, integration and superposition of information layers. Three algorithms used in GIS spatial analysis include spatial superposition algorithm (Fischer, 2019), attribute classification algorithm (Jia, 2017; Shirowzhan et al., 2019) and algorithmic spatial interpolation (Comber, 2019). The hierarchical analysis model will support GIS, synthesize information, assign the most appropriate weights to the selected elements. After the factors have been hierarchical and weighted, integrating them will give us the landslide susceptibility index. Using the overlay tool in QGIS for the edited maps, new maps are formed and weighted to create a landslide susceptibility index map. After being divided according to appropriate influence levels, a landslide hazard map will be formed in the study area.

4. RESULTS AND DISCUSSIONS

4.1. Research overview on 3S technology application in disaster risk management in the northern mountainous region of Vietnam

3S technology with outstanding advantages compared to traditional methods in disaster risk management research, especially in establishing zoning maps, assessing and warning levels of disaster risk. The use of 3S technology with comparison with statistics brings positive, quantitative and highly accurate results. This result contributes to support for managers in the prevention and mitigation of impacts caused by disaster risks. Therefore, right from the 1990s, 3S technology (mainly Remote Sensing and GIS) has been applied in studies on disaster risk management in mountainous areas of Vietnam. Initial studies mainly used remote sensing images to collect background data (topography, slopes, vegetation, rivers) for the study of disaster risk factors (La, 2009). GIS technology supports the establishment of zoning maps and disaster warnings. GPS technology supports field investigations and data collection (Tran, 2020).

The beginning of the twenty-first century is the period of strong development of geoinformatics technology, the application of 3S technology in researches and projects related to disaster risk management in mountainous areas. variable. Applied studies do not stop at analyzing and describing the current status from spatial data. The combination of tools in the 3S component has allowed users to integrate the functions of data collection, spatial analysis, zoning, assessment and precise location of disasters. The Vietnamese government has paid attention and invested in projects and research topics at all levels on the investigation and monitoring of disaster risks using 3S technology. For example, research and application of 3S technology to warn of natural disasters, including landslides in Hoa Binh province (Nguyen, 2003); research on establishing landslide susceptibility maps in Northwestern border provinces using remote sensing and GIS technology (Nguyen et al., 2008).

During the period 2011-2015, the Asian Development Bank supported Vietnam to implement the project "Application of remote sensing technology in flood forecasting, warning and monitoring". The project has applied 3S technology in flood management, monitoring and forecasting in river basins, applied in Phu Tho province. The monitoring system is established through remote sensing activities, the information is transmitted to and sent to the local command board for flood and storm control via text message (SMS). On the basis of the information received, the local government has a plan to relocate people, to reduce the impact of natural disasters. In 2016, the project "Investigation, assessment and zoning for landslide hazard warning in mountainous areas of Vietnam" in 10 northern mountainous provinces using 3S technology. The total investigation area of nearly 60,000 km^2 has identified nearly 9,000 landslide points of different sizes and levels of danger; nearly 3,000 questionable slip points were discovered from analyzing the terrain on digital stereoscopic models and interpreting aircraft images. The main product of the project is the current map of landslides and rocks at the scale of 1:50,000; Spatial and Web-GIS database structure of landslides (Vietnam's Ministry of Natural Resources and Environment, 2018).

In addition to the projects, there have been many studies and applications of 3S technology in monitoring, monitoring, prevention and mitigation of natural disasters. For example, research and application of 3S technology to warn of landslides in Son La province (Nguyen, 2003); research to establish disaster risk maps for northern mountainous provinces by remote sensing technology (Du, 2009); research and application of geoinformatics technology to warn of landslides in Hoa Binh and Son La hydropower reservoirs (Nguyen, 2015); application of radar remote sensing images (Sentinel, Alos PALSAR) established flood map for downstream Tra Khuc river basin (Nguyen et al., 2017); applying geoinformatics technology to build an early warning system for flash floods in mountainous areas, testing it in Thuan Chau district, Son La province (Lai, 2018); application of 3S in constructing a flash flood warning model in northern mountainous regions of Vietnam: a case study at Trinh Tuong commune, Bat Xat district, Lao Cai province (Kieu and Tran, 2021), and flash flood hazard mapping using satellite images and GIS integration method: a case study of Lai Chau province, Vietnam (Kieu, 2021).

In recent years, 3S technology has been widely applied, as an indispensable method in management, monitoring, warning and assessment of damage caused by natural disasters in Vietnam. Some key projects are currently working towards application, for example the project of applying remote sensing technology and GIS to assess some elements of environmental resources for warning, prevention and mitigation of natural disasters, piloted in Quang Ninh province (Vietnam's Ministry of Natural Resources and Environment, 2020); Research on building a warning model and zoning flash flood risk on the basis of integrating artificial intelligence, data and geoinformatics technology, experimentally applied to Lao Cai province (Vietnam's Ministry of Science and Technology, 2020); Application of remote sensing, GIS, GPS technology in surveying and mapping for flash floods and landslides in the Northwest region of Vietnam (National Science and Technology Fund, 2021).

The literature review shows that the research and application of 3S technology in disaster risk management in mountainous areas of Vietnam is quite developed. However, researches still have some limitations: The first limitation is most of the studies are stopping at using 3S technology as a research tool, in which remote sensing provides data, GIS for spatial analysis, GPS for positioning; The ability to combine to build synthetic models is limited. The second limitation is lack of applications capable of online connectivity, dynamic data mining, opensource software applications, webGIS, big data and artificial intelligence. This is a huge limitation, because disaster risks often occur very quickly, requiring online data in disaster monitoring alerts. The third limitation is Vietnam does not have uniform standards on disaster risk data. The data has not been synchronized, making it difficult to use and inherit research data. Another difficulty is the cost of applying 3S technology in research is often very large, especially the cost of data collection. In the economic conditions of Vietnam, especially the mountainous provinces will face many difficulties when building research projects with high technology applications.

4.2. Prospects of 3S technology application in disaster risk management in the northern mountainous region of Vietnam

Natural disaster risks in the northern mountainous region of Vietnam tend to increase due to human impacts and the effects of climate change. Applying 3S technology can build disaster risk prediction and warning models. The analytical data from the 3S model is a decision support tool for disaster risk management and monitoring. With the strong development of science and technology, especially geospatial technology, the prospect of 3S technology application in disaster risk management in the northern mountainous region of Vietnam is reflected in the following fields:

(1) The prospect for disaster risk database construction: Database in disaster risk management is very important. Currently, with the strong development of remote sensing technology, the data is very diverse, the resolution and accuracy are getting higher and higher. Spatial positioning data from GPS devices are increasingly complete, with high coverage and precise spatial positioning capabilities. Besides, with the explosion of opensource GIS software, allowing users to access, collect and process data from many different sources (Reznik et al., 2017). This is a great prospect in building a 3S database system for forecasting, warning, zoning and disaster risk management in the northern mountainous region of Vietnam.

(2) The prospect for disaster risk spatial analysis: Disaster risk management, the first goal must be to manage the disaster risk space. In which, it is necessary to partition, decentralize, identify locations, locations and spaces that are frequent or likely to occur. Today's GIS software has very good spatial analysis capabilities. Input data ensures accuracy, specialized software is capable of analyzing data, accurately determining the space of disaster. The northern mountainous region of Vietnam often occurs types of natural disaster risks such as flash floods, pipe floods, and landslides. These are types of natural disasters caused by natural factors such as topography, slope, soil thickness, vegetation cover characteristics, rainfall, combined with human factors such as farming methods, measures to plant and protect forests, to build civil works.

Currently, GIS software (ArcView, ArcGIS, QGIS, SuperMap, ...) is capable of analyzing the superposition of agent elements, partitioning, assessing the extent and spatial forecasting of the probability of disaster risk.

(4) The prospect for disaster risk forecasting: Disaster risk forecasting depends on forecasting the factors that occur that type of disaster. In mountainous areas, except for fixed factors (geology, topography), most types of disaster risks can be predicted in advance on the basis of sudden factors such as rainfall, decline vegetation cover, displacement of rock masses, the appearance of underground runoff. Currently, data from satellite images, aircraft images and navigation devices allow for relatively accurate forecasting and calculation of fluctuating factors causing various types of disasters. Typically, flash floods in the northern mountainous areas of Vietnam are mainly caused by heavy rains, combined with topographic factors on steep areas, and loss of vegetation (Lai et al., 2018). Based on satellite images, it is possible to forecast rainfall and calculate the possibility of flash floods in a certain area.

(5) The prospect for online disaster risk warning: Currently, with the support of devices capable of providing online data, connecting to online software on mobile devices allows setting up online disaster warning systems. The cost for the online disaster risk warning system is not too large, it is completely possible to set up the system at high-risk points. This is a great prospect of 3S technology applied in disaster risk warning in the northern mountainous region of Vietnam.

4.3. Experimental research model: A case study of landslide zoning and warning in Lai Chau province of Vietnam

To clearly see the prospect of 3S technology application in disaster risk management in the northern mountainous region of Vietnam, the report presents simulation results of 3S technology application model in landslide zoning and warning in Lai Chau province as an illustrative example.

Lai Chau is a typical mountainous province of Vietnam, has 9068.78 square kilometers, 8 administrative units including Lai Chau city and 8 districts of Muong Te, Sin Ho, Nam Nhun, Tam Duong, Phong Tho, Tan Uyen, and Than Uyen. The province has more than 400 thousand of people of 20 ethnic groups living together, in which Thai ethnic people cover the majority of population in Lai Chau with 131.822 people, accounting for 34% of the total population. The other ethnic groups consist of Mong people 86.467 people (22.30%), Kinh ethnic group 54.027 people (13.94%), Dao ethnic people 51.995 people (13.41%), Ha Nhi ethnic people 14.658 people (3.78%) and other ethnic minorities. Local people mainly plant corn, cassava, upland rice, herbs, and etc on hills and wetland rice in valleys, while they also do exploitations in forests (Statistical Office of Lai Chau Province, 2022). These forms of agricultural cultivation are completely free and much dependent on natural conditions, leading to an incline in terms of landslide potential and subsequently increasing damage. According to statistical data, in the term from 2001 - 2021, the locality has 219 landslide points. Through investigations and surveys, landslide forming factors in the research location are relatively typical with the characteristics of basins, partitioned terrains, high slopes, and flows that tend to aggregate. Moreover, in recent times the forest vegetation cover of Lai Chau tends to decrease; combined with the unsustainable form of agricultural cultivation of the people, the impact of climate change, erratic heavy rain, ... increases the intensity and impact of landslide.

From actual data, combined with research results on landslides of related studies in mountainous areas of Vietnam (Nguyen et al., 2008; La, 2009; Nguyen, 2015), the empirical research model has identified 6 factors forming landslide in Lai Chau province, including slope, daily rainfall, soil type, current land use status, geological background and topographic dissection. 3S data serving landslide warning zoning was built on the basis of data analysis of 6 factors that cause landslides in Lai Chau province. Each element is classified, the density of points/square kilometer is calculated, and the weights for each element are calculated in **Table 1**.

Table 1.
Classification and weighted values of landslide-generating factors in Lai Chau province.

Factor	Subclass	Density of points/km^2	Weight	Factor	Subclass	Density of points/km^2	Weight
Slopes (Degree)	Below 10	0.025	0.015	**Current land use situation**	Natural forest	0.002	0
	10-20	0.075	0.058		Plantation forest	0.069	0.025
	20-30	0.120	0.215		Poor forest	0.135	0.852
	30-40	1.135	0.258		Shrubs	0.981	1.325
	Above 40	0.105	0.095		Agricultural land	1.126	0.296
Rainfall/ day (mm)	Below 25	0.102	0.015		Residential land, specialized land	0.687	0.558
	25-50	0.150	0.025		Rocky mountains	0.054	0.032
	50-75	0.128	0.060		Water surface	0.005	0
	75-100	0.098	0.122	**Petrology**	Disjointed rock group	0.012	1.252
	100-125	0.042	0.217		Carbonate rock group	0.028	0.527
	125-150	0.072	0.348		Metamorphic rock group	0.056	0.321
	150-175	0.085	0.879		Sedimentary rock group	0.126	0.213
	Above 175	0.068	1.759		Eruption rock group	0.098	0.122
Soil type	Mountain limestone	0.015	0.242		Intrusive rock group	0.056	0.098
	Alisol	0.124	0.156		Quaternary rock group	0.037	0.052
	Mountain humus	0.028	0.269	**Deep cleavage (m)**	Below 100	0.12	0.035
	Dark soil	0.098	0.196		100-200	0.212	0.521
	Oxisols	0.159	0.127		200-300	0.145	0.265
	Ferralsols	0.214	0.568		300-400	0.085	0.132
	Strongly erosive soils	0.037	0.055		400-500	0.039	0.086
	Aggregating sloped soils	0.026	0.012		Above 500	0.012	0.012

Overlapping 6 types of maps, corresponding to landslide-forming factors in Lai Chau province according to formula (1), obtain a landslide risk map of Lai Chau province with 5 levels as follows: very low (LSI $\leq$ 0.1), low (LSI = 0.1-0.2), medium (LSI=0.2-0.3), high (LSI=0.3-0.4), very high (LSI $\geq$ 0.4) (**Fig. 1**).

The results of spatial analysis show that Lai Chau province areas with very high risk of landslides is 753.62 km^2 (accounting for 8.31% of the area), distributed in areas with sloping terrain and loose soil layers, the vegetation cover is low, the largest area is in Phong Tho, Muong Te, and Nam Nhun districts. The area assessed as having a high risk of landslide is 1633.29 km^2 (accounting for 18.01% of the area), scatteredly distributed, the most is Muong Te district with 786.51 km^2. The area assessed to have a medium risk of landslides is 3097.9 km^2, accounting for 34.16% of the province's natural area.

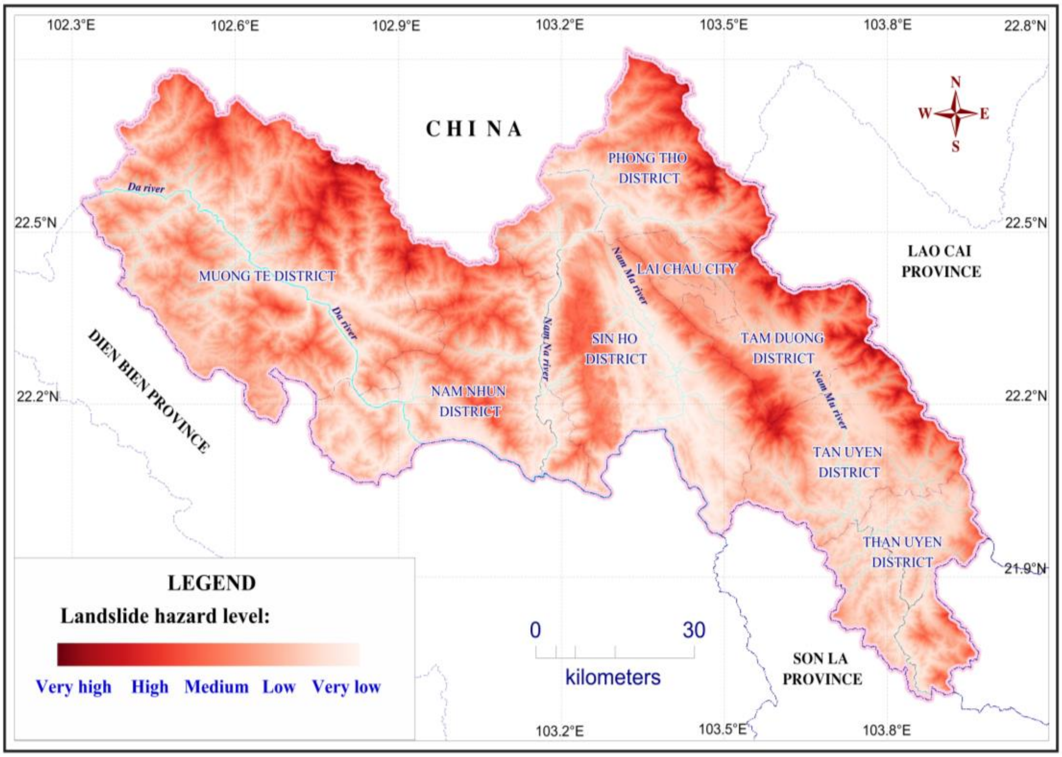

Fig. 1. Mapping of landslide risk in Lai Chau province.

Areas with small slopes, vegetation is planted or natural forest, low terrain fragmentation, often basins with geological strata of sedimentary rocks are assessed as low risk of landslides and very low risk of landslides. In Lai Chau province, the area with low landslide risk accounts for about 25% of the area, and the area with very low risk of landslides accounts for 14.56% of the area (**Table 2**).

Table 2.

Classification of landslide levels in Lai Chau province.

Hierarchy	Intensity	LSI score	Area (km^2)	Proportion (%)
Level 1	Very low	≤ 0.1	1320.41	14.56
Level 2	Low	0.1 – 0.2	2263.57	24.96
Level 3	Medium	0.2 – 0.3	3097.90	34.16
Level 4	High	0.3 – 0.4	1633.29	18.01
Level 5	Very high	≥ 0.4	753.62	8.31

The results of landslide classification in **Table 2** are consistent with the results of field surveys and reports related to landslides in mountainous areas (Vietnam's Disaster Prevention and Control Office, 2021). The landslide sites all coincided with areas assessed as high and very high risk of landslides. Areas with high and very high risk of landslides are studied in detail, combining the results of the current survey to define landslide warning zones. On warning points, set up analysis equipment and online landslide warning. Online locators and analyzers (mainly daily rainfall data) collect landslide-causing data to generate online landslide warning information.

4.4. Some solutions to develop the application of 3S technology in disaster risk management in the northern mountainous region of Vietnam

Based on the above analysis, the study proposes a few solutions to develop the application of 3S technology in disaster risk management in the northern mountainous region of Vietnam, the solutions are as follows:

Firstly, it is necessary to study, evaluate and categorize types of natural disaster risks. The mountainous area in the North of Vietnam has a large area and complicated types of natural disasters. To apply 3S technology for disaster risk management, it is necessary to make preliminary assessment and classification of disaster risk types. This is also a limitation when previous studies have not been able to solve it (Vietnam's Ministry of Natural Resources and Environment, 2020). Develop a theoretical basis, a scientific basis and an application model suitable for each type of disaster risk is one of the important solutions that should be prioritized.

Second, it is necessary to build a synchronous, comprehensive and modern 3S database. Building a database is an important solution and should be given top priority. Currently, the biggest difficulty when applying 3S technology in Vietnam in general and in mountainous areas in particular is the lack of database. The satellite image data in Vietnam is still not active, the current satellite images have low image resolution, especially the level of updating and synchronizing the image database is still limited. GPS data also depends on handheld devices, the accuracy is not high. GIS data is not synchronized, depending on traditional data sources; digital data sources are limited.

Third, it is necessary to build infrastructure and human resources in the field of 3S technology. In which, it is necessary to develop infrastructure and human resources for mountainous areas in stages. First, priority should be given to developing a system of satellite base stations, combining automatic warning systems, and building disaster risk management webGIS in high-risk areas. The staff and specialists have very limited qualifications and understanding of 3S technology. Therefore, it is necessary to strengthen human resources by organizing conferences, seminars, publishing documents and in-depth training. Can establish mechanisms to network and promote public awareness; Exchange and train professional staff through technical transfer training courses.

Fourth, it is necessary to develop an online application model system to warn and manage disaster risks. Natural disasters often happen very quickly, so it is necessary to have an online warning system. In which, it is necessary to exploit the system of sensors, online satellite images, webGIS system associated with application software on mobile devices. Online application models have the ability to quickly analyze and provide accurate information to help managers and people have early plans in disaster risk prevention.

5. CONCLUSIONS

3S technology is very promising in disaster risk management in the northern mountainous region of Vietnam. Application of 3S technology can build databases, perform spatial analysis algorithms, build forecasting models and warn of disaster risks. The analytical data from the 3S model is a decision support tool for disaster risk management and monitoring for mountainous areas. Experimental research model applying 3S technology in building landslide warning zoning map in Lai Chau province is a proof of the potential application of 3S technology in disaster risk management. In the future, to develop 3S technology, it is necessary to build a synchronous database, develop human resources, and at the same time need to build online application model systems.

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