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SLOPE FAILURE ASSESSMENT IN DAM THUY COMMUNE, TRUNG KHANH COUNTY, CAO BANG PROVINCE BY GEOLOGICAL AND WEATHERING CHARACTERISTICS

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Abstract

Slope failures are very common natural problems in the mountainous terrain due to the steep topography, improper landuse and adverse climatic conditions. In every geohazard study, detailed investigation on the geological structures, surface features and other related variables will be carried out. This paper discuss the impacts of geological and weathering properties as environmental factors for assessing slope failures in mountainous terrain. A case study from Dam Thuy commune, Trung Khanh county, Cao Bang province is used to illustrate the dynamic interaction between landsliding factors and slope failures. Regional survey results include underlying geology, surface forms and features, and weathering process in study area. Methods used to analyse the geologic, geomorphic and weathering characteristics of Backan town area include a combination of remote sensing image interpretation, field mapping, soil/stratigraphic descriptions, and the use of previously published surveys. The collected data then can be combined to create landslide hazard and risk maps for study area.

Keywords: Geological Hazards, Slope Failure, Landsliding Factors, Dam Thuy Commune, Cao Bang Province.

1. INTRODUCTION

Every year, millions of people around the world are losing their lives in natural disasters, which have large impacts on the local and global economy. Almost no portion of the earth's surface is free from the impact of natural hazards and more people are affected by disasters due to increasing population densities and uncontrolled development.

Landslides are generally isolated processes which individually may not be very large in size but can occur with a high frequency in a region and cause substantial damage to life and property. Over the years it is expected that landslides will cause more damage to properties than any other geological hazard (Varnes, 1984; Petley et al., 2005).

Floods and landslides are among the most destructive natural hazards in Vietnam, especially the mountainous terrains. Recent global disaster assessment studies (Petley et al., 2005; Nadim and Kjekstad, 2009; OFDA/CRED, 2010) reveal that the countries with the highest risk to such disasters are mostly in the developing world. According to the total landslide fatalities reported worldwide in the last decade, Kirschbaum et al.

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(2010) confirm that the developing countries account to about 80% and Vietnam is among the highest risk countries.

2. LANDSLIDE DYNAMICS

2.1 Landslide factors of geological and weathering variables

Landslide dynamics are governed by a combination of variables which exist in differing amounts and levels of importance according to local conditions. Many factors contribute to the instability of slopes, but the main controlling factors are the nature of the underlying bedrock and soil, the configuration of the slope and groundwater conditions. Geological, weathering and geomorphic forces acting upon the landscape determine the order of importance for landslide processes, and often interact differently based on what combination of variables are present. These variables can be classified as static factors in modeling slope failure (Dai and Lee, 2001), where they provide the base environmental conditions within a landscape, conditions which tend to remain unchanging over a period of time. When static variables do undergo change, these are generally slow, or occur in geologic time (Dai and Lee, 2001).

The role of the bedrock geology in the landslide event is critical but indirect (Creighton, 2006). Lithology and rock/soil properties are the most used parameters extracted from geology. The presence of the high ground and slope profile is controlled by the underlying geology, the folding and faulting have resulted in the current relief, which can be represented by regional slope and topography. The nature conditions, particularly under tropical weather, can create thick weathering crust that is susceptible to slope failure pose significant problems to both existing and future development in mountainous areas.

These static variables represent the basic items which need to be accounted for in any slope stability model, especially when combined with dynamic variables such as intense seasonal rainfall and/or human landscape modification.

2.2 Human impact on landsliding processes

The manner of human impact has ranged widely in recent years, but a brief list of common modifications could be identified as resource extraction, clearing of forest for agricultural uses and settlement or urbanization (Guzzetti et al., 1999; Glade, 2005). Many of the problems found in human-induced impacts on the landscape can easily be seen through different types of erosion. Subsidence in the soil profile caused by land clearance often precedes a larger, violent mass movement of soil colluviums on weathering regolith associated with road and housing cuts without proper support for the slope.

Human impact is an important triggering factor for landslides. Generally human-induced landslides have very high economic consequences (closing the roads, disruption of daily routines, etc.). The costs of these failures are much widely distributed so that total losses attributable to landslides are growing rapidly.

In Vietnam, the effects of human activity are also greatly and collected information proves that claim. Slope instability may result directly or indirectly from the activities of people.

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Failures can be triggered by construction activity that undercuts or overloads dangerous slopes, or that redirects the flow of surface or groundwater. People increase the risk of landslides by modifying the landscape as building on unstable slopes or in the path of potential landslides.

3. CASE STUDY FROM DAM THUY COMMUNE, TRUNG KHANH COUNTY, CAO BANG PROVINCE

Dam Thuy commune located in northern part of Vietnam, close to the border with China and about 330km from Hanoi, the capital of Vietnam. The area is known as one of the most landslide-prone areas in Vietnam.

The commune locates at the east valley of Quay Son River and close to the Ban Gioc Waterfall, an impressive natural sights of Vietnam and one of the most beautiful cross border in the world. Surrounding hills are mostly northwest-southeast direction with round peaks at 500-600m and steep slopes. The whole area is covered by carbonate rocks with different karst features. The study area locates in the tropical monsoon area with two distinct seasons. The wet season begins in April and continues to October, with July and August being the wettest months which get heavy rainstorms (Nguyen Quoc Phi, 2022).

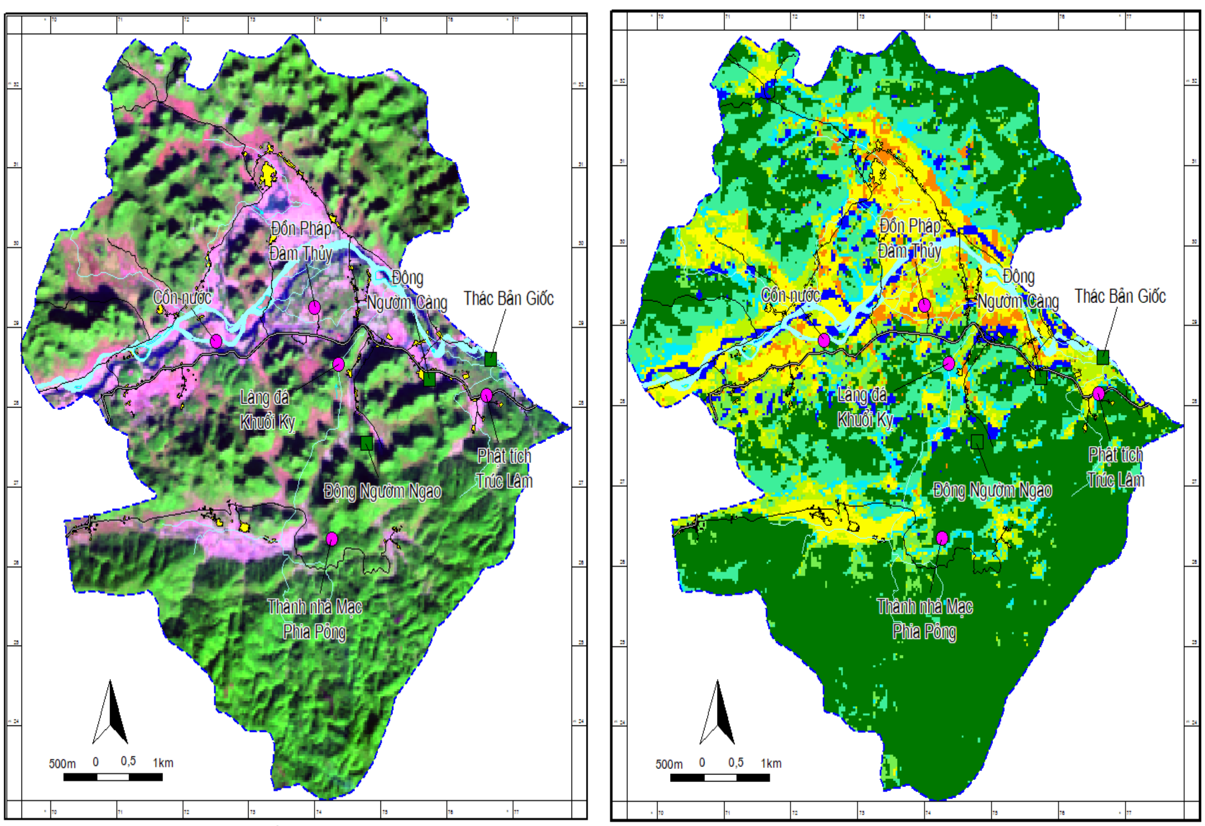

Figure 1: Remote sensing image and landuse map of Dam Thuy commune.

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3.1 Bedrock geology and surface landforms

The stratigraphy of study area composes of limestones of Na Quan formation (D_1-D_2*nq*), Ban Coong formation (D_2*bc*), Mia Le formation (D_1*ml*), metamorphosed shales, siltstones, claystones of Than Sa formation ($\in_3$ts) and Quaternary deposits (Q). The area is lying near a big northwest-southest fault with an area of about 46km^2. Fault systems of study area illustrate the complicated development of tectonic phases with distinctive fault zones of NW-SE and sub-latitudinal trends. Based on its origins, the landform of study area can be classified into different terrains:

- Karst terrain distributes mostly at the center and northern part of study area. It develops on carbonate rocks of Na Quan, Ban Coong and Mia Le formations at the elevation of 500-600m, sometimes 650-700m and typifies by sawtooth form topography. Steep slopes at 45-50^0 and over are very common. Dissolved process occurs on the surface or follows the cracks of fractured zones or faults. Carbonate rocks can be dissolved by groundwater and karst terrains are often characterized by sawtooth topography with sinkholes and springs. Therefore, foundation on karst topography should be aware to prevent surface subsidence.
- Erosion-denudation terrain distributes in the south of study area, account for about 20% of the area with the elevation ranges from 450m to 550m, making a typical hilly surface of study area. Underlying bedrocks of this terrain are metamorphosed shales, siltstones, claystones of Than Sa formation. The rocks are highly folded and experience faulting activities. The topography characterizes of rounded peaks, gentle slopes with slope angle of 30-50^0, and a thick weathering depth.
- Accumulation terrain: Geomorphic landforms such as stream terraces and alluvial deposits record sedimentary processes in a river system. River terraces as small cultivated strips in study area are principally conglomerate, granule, gravel, sand, clay, and loam in various combinations.

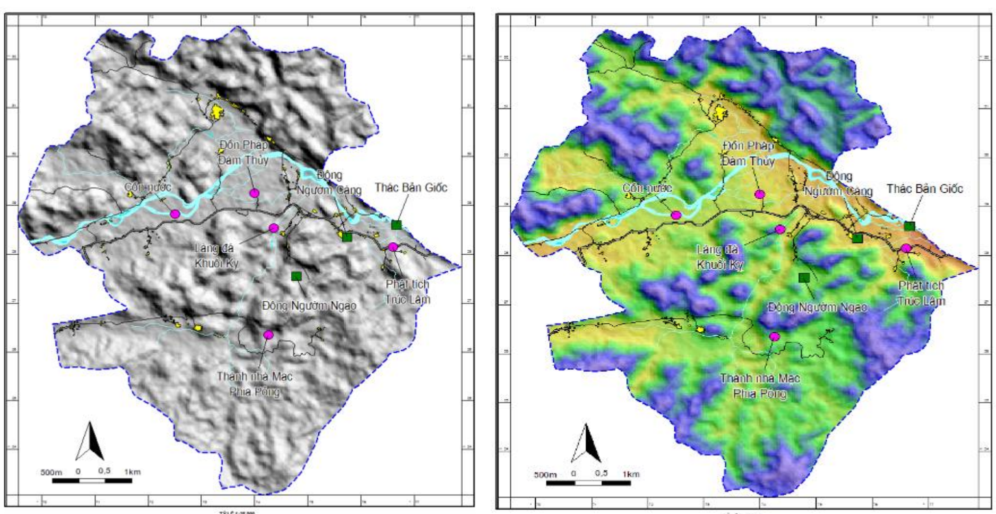

Figure 2: Topographics and landform of study area.

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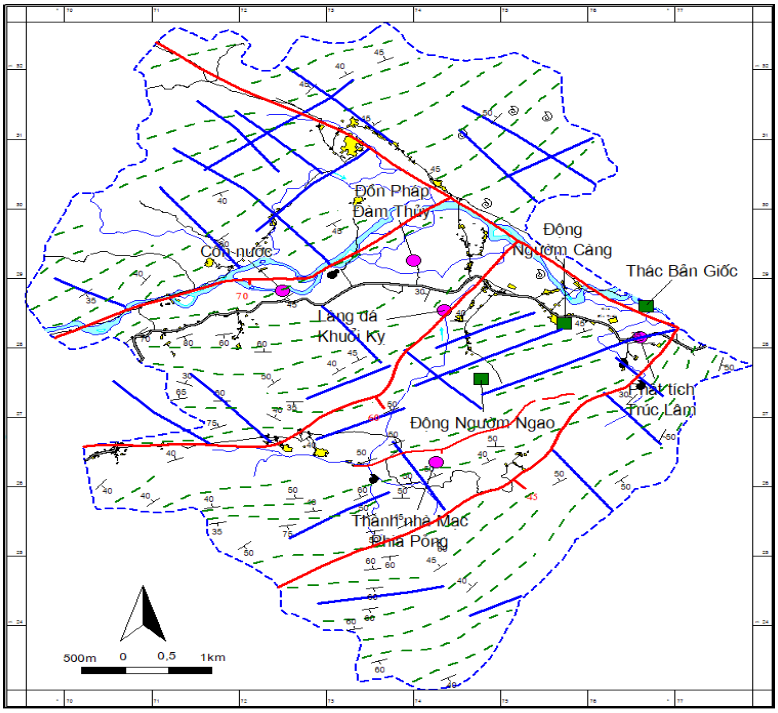

Figure 3: Structural features of study area.

3.2 Weathering characteristics

In Dam Thuy and surrounding area, weathering effects can also be recognized in the limestone itself. As Nguyen Quoc Phi et al. (2022) described, this is especially apparent as an increase of secondary porosity of the material, most notably through crack formation resulting from dissolution attacking the most vulnerable layers present in the bedding structure of the limestone.

Field investigation of outcrops and typical cross sections shows incomplete weathering crust along rock slopes. However, in the south of study area where the Than Sa formation ($\in_3$ts) located, a mature weathering of bedrocks has produced a thick crust down to 10-15 meters and over below the surface. The weathering crust of study area is rarely entire preserved, especially on limestone mountains, due to erosion and redeposition and it can be described as follows from top to bottom:

- Residual soil zone (edQ): The depth of residual soil zone ranges from 0.1 to 0.5m and up to 1-1.5m in some places, such as old landslides. It composed of the mechanical and chemical weathering products of Than Sa formation, where sand, clay, granule, gravel and rock fragments are mixed with organic material of tree remnants and their roots. The materials is in grayish, loose and low cohesion form.
- Colored clay (lithoma) zone is distributed right below residual soil zone and can be divided into two subzones:

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+ Upper clay subzone: 1-3m depth, composes of clay, sandy silt, completely weathered shale, schist, silty sandstone in yellow-brownish color. The materials are derived from the chemical decay of feldspar or clay-bearing rocks, and original texture of bedrocks is completely demolished.
+ Lower clay subzone: composes of clay, silty clay, sandy silt and highly weathered rocks with a very massive texture in white grey, yellowish or brownish color. Its thickness may vary between 3 and 4m. The color of bedrock has been completely changed, but traces of rock texture are still well preserved. Clays are low cohesion and can be squeezed by hand.

- Saprolite zone: can only be seen on cut slopes or in landslide bodies with an average thickness of 5-8m, sometimes 10-15m. This is weathered bedrock where the texture is still retained with primary rock minerals less resistant to weathering such as clay minerals and iron-hydroxides, have been altered to secondary minerals.
- Bedrock zone: is, in fact, including transition zone and fresh rocks of limestone area. This is the zone of transitional material grading from slightly weathered rock to fresh rock. Its thickness varies differently.

Weathered materials can also be found along faults and other major discontinuities inside limestone mass, including some contacts between geological units.

Human activities are also created human-induced geomorphologic features in Dam Thuy. One special characteristic of the area and surrounding area is the absence of large gullies, expected from the impact of intense rainfalls. Considerable landscape modification accompanies urbanization was a contributing factor in slope instability. In fact, over 80% of the slope failures in study area involved one or more of the human causes. Hillside excavations, primarily roadcuts and construction activities, are major threats to the stability of slopes at the area.

4. DISCUSSIONS AND CONCLUSION

An understanding of the geologic causes of the slope instabilities in Dam Thuy requires some knowledge of regional geology. In study area, the role of the bedrock geology in the landslide event is critical but indirect. The different hardness of adjoining formations, such as hard limestones and more easily weathered shales, has resulted in the stepped crust of the hillside. The NW-SE trending and sub-latitudinal faults, which may contain material which is easier to erode than the surrounding rocks, forms part of the course of the Quay Son River and surrounding streams. Another important factor is that the limestones of Na Quan, Ban Coong and Mia Le formations, which account for over 80% of the area, are mostly high permeable, thus have a lower run off rate during rainfall compared to more permeable rocks of Than Sa formation.

The collaped rock slopes generally occurred on limestone mountains and landslides occurred where surficial debris (including slope wash, artificial fill, and vegetational debris) rested on relatively impermeable deposits s. Slope debris lying atop such poorly

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permeable materials can readily become saturated during heavy rains, because the water cannot seep rapidly into the underlying material. When surficial debris on a hillslope becomes saturated, seepage forces acting within the mass reduce the stability of the material. If the material had previously been in a condition of marginal stability, it may slide.

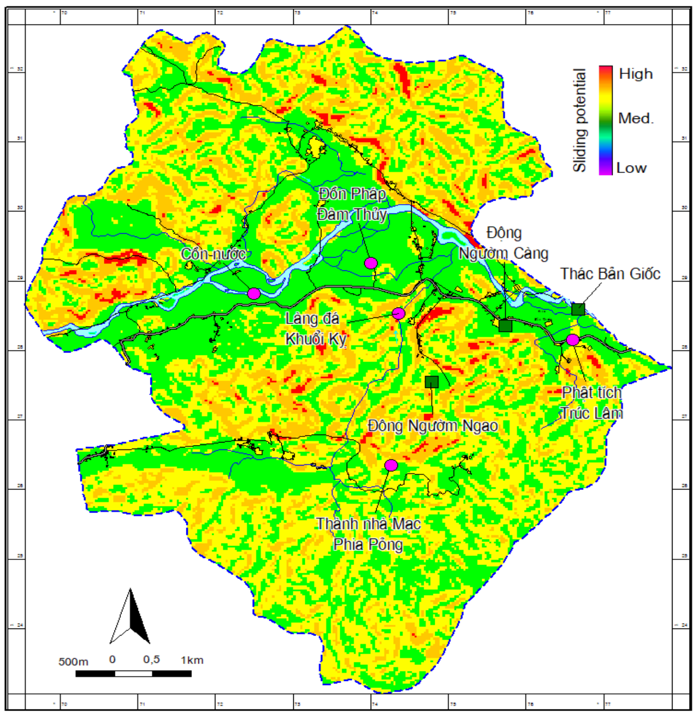

Figure 4: Sliding potential of Dam Thuy area.

The analysis of causal factors from geological, weathering characteristics and human impact on slope instability processes gives a better understanding of the dynamic interaction of the factors involved with the failures in karst terrains like study area. These factors were determined to be significant in landslide initiation and can be combined to indicate areas of moderate and high risk on hazard maps.

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