ENGINEERING GEOLOGICAL ANALYSIS FOR LANDSLIDE SUSCEPTIBILITY MAPPING IN GIA NGHIA VOLCANOUS AREA, DAK NONG PROVINCE, VIETNAM

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1. Introduction

Landslide is one of the geological hazards that commonly occur in tropical areas, especially in rainy season in the mountainous regions. Sometime, landslide is the impact of earthquake, volcanic, tectonic actions, human activities, etc. Their consequences are serious threats to mankind, economy, society and environment. Deaths, injured, collapse of infrastructures and so on are thing cannot avoid. Problems bring out such as: where and when will landslide happen? How the community can know which part of their living area is susceptibility for landslide? These are series of questions which need defined to avoid such substantial loss and also to prevent and minimize if as landslide occur. To do something like that, hence, there is a need for landslide susceptibility mapping for identification of potential landslide zones. Landslides are the result of complex interaction among several factors, primarily involving geological, geo-morphological and meteorological factors. The spatial information related to these factors can be derived from remote sensing data, ground based information, and several other data sources. Geographic Information System (GIS) is a very powerful tool for the integration of different types of data. Over the past few years, there have been significant developments of GIS for spatial data analysis. Efficient landslide susceptibility mapping can be carried out by combining GIS with image processing capabilities (Sarkar and Kanungo, 2004).

2. Research objectives

The topic will develop landslide susceptibility mapping in the study area which control of geomorphology, lithology and geological structure conditions.

3. Limitations of the research work in the study area

- Research area is about 24km^2, but just existed two boreholes of drilling log KGN 09 and drilling log KGN 10. Therefore, they are not performed the completeness of characteristics of engineering geological overall the area yet (soil parameters, groundwater table, etc.).

- The limitations of information of landslide distribution in the past; hence, a qualitative map combination approach is selected for analysis where relative weighting values and scoring values are assigned to the factors and their classes that based on the basic of field knowledge and experience and so on.

4. Location of the study area

This study focus on Gia Nghia area (*Figure 1*) which lies within latitude 12°00’20”N to 12°01’09”N and longitude 107°41’10”E to 107°41’52”E (grid coordinates, X = 1.328.000 to 1.332.000 and Y = 18.790.000 to 18.796.000 - Pulkovo 1942 GK Zone 18N) and covers an area of about 24km^2. Dak Nong province is about 500m above the sea level. The study area is traversed by many ridges and valleys. The major ridges are at elevations of about 675m to 760m while valleys range in elevation from about 560m to 605m. The maximum elevation in the area occurs at Northeast (NE) and Northwest (NW) (about 760m). The minimum elevation occurs at the central of the study area (about 560m) (*Figure 2*).

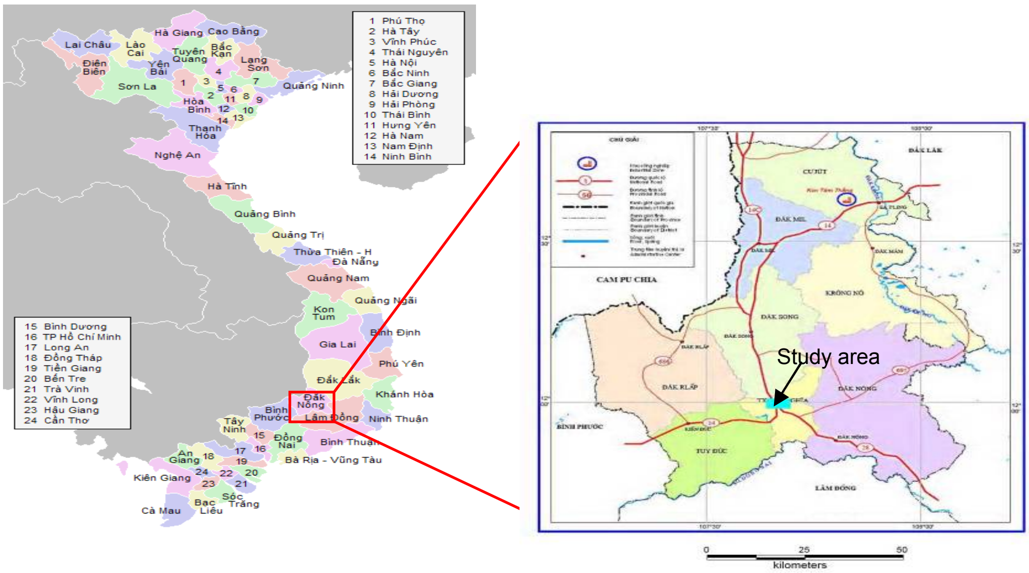

Figure 1. Location of the study area

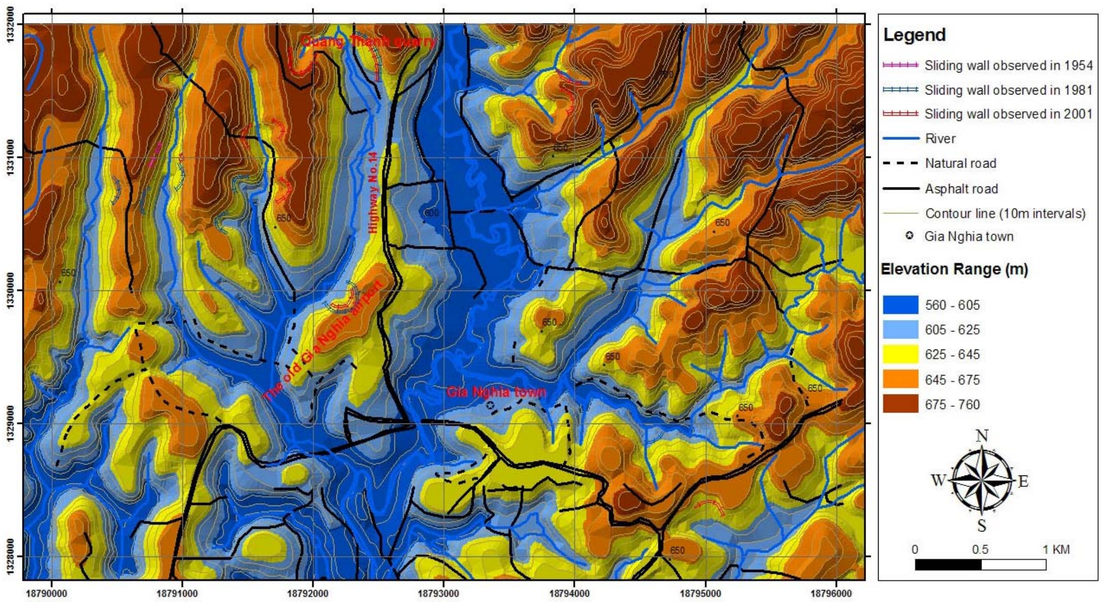

Figure 2. Digital Elevation Model (DEM) of the study area

5. Geology

5.1. Lithology

According to Vu et al., 2006, almost the study area is covered by basalt layer during Neogene to Quaternary; somewhere exposed Early - Middle Jurassic sediments in West (W) and Southeast (SE). Thickness of basalt cover changed from 500m nearly Vietnam - Cambodia's boundary and about 100-120m in the central of the study area with 2 phases and the boundary of phases were weak zones or sedimentary layers where were discontinuous and inhomogeneous structures, etc. According to previous researchers, in the study area landslide occurred on weathering crust of basalt and may be still continuous occurrence in the future. For example, observation of sliding body section of the old Gia Nghia airport as *Figre 3*.

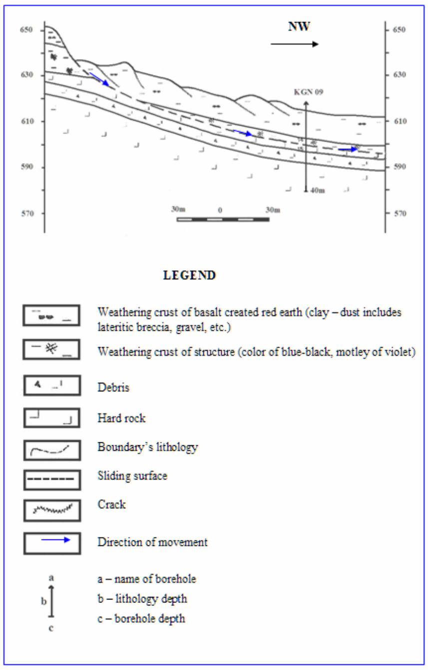

Figure 3. Sliding body of the old Gia Nghia airport (modified after Vu et al., 2006)

5.2. Geological structure

According to some researchers, the study area is marginal southern part of Bu Prang basalt eruption dome. Dome radius is about 50 to 80km. In the dome center, thickness of basalt forming is more than 500m; the bedrock face is concave-down in 500m high/the sea level (Nguyen et al., 1999). In Gia Nghia area, the thickness of basalt forming is less than, 100m approximation, the bedrock face under basalt layer is approximate 560-600m high/the sea level. The mainly of component of basalt eruption forming is olivine basalt with the structural of massive basalt and vesicular basalt. In the study area, the basalt structure is very complex with a stratification of alternateness layers of massive basalt and vesicular basalt; somewhere is basalt breccias, etc. In addition, according to researchers, within volcanic eruption process as well as after volcanic eruption, cracks system and faults systems created. In particular, many cracks systems were generated surrounding volcanic craters on the ground surface; some zones within 0-130m, some zones within 0-170m. Mass of soils/ rocks was a furious breakdown in these zones. Therefore, this is also a cause to develop weathering crust forming of basalt. Hence, landslide occurrence in the study area related to volcanic structure (*Figure 4*). Volcanic structure understood as eruption dome, hollow, volcanic crater, simpleness stratification or complexity as well as faults and cracks of the ring or radial shape that concerned with them (Vu et al., 2006). Researchers were divided volcanic structure into stratification of volcanic structure and brokenness of volcanic structure which defined as following:

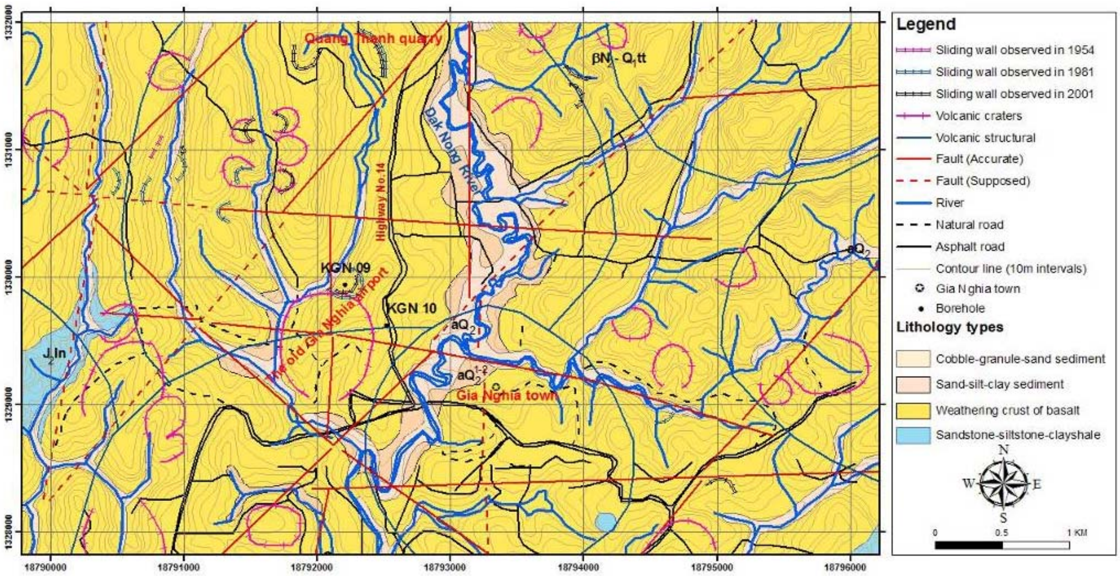

Figure 4. Geological map of the study area (modified after Vu et al., 2006)

- *Stratification of volcanic structure:* was formed due to volcanic formations of different phases is superincumbent chronologically down-up which is young gradually formations. In every phase of volcanic eruption may form cones or arcs of material accumulation and lava flows due to volcanic eruption. In lava flow has a differentiation according to vertical direction, etc.

- *Brokenness of volcanic structure*: When volcanic eruption, volcanism blasting power is very big, they will break rock/soil mass surrounding area and created cracks, faults; cracks systems created on the surface; density of radial cracks and ring cracks are more than other surrounding areas. Volcanic crater areas are usually collapses due to movement of magma underground after eruption. Their characteristics are slopes, cliffs which reflected fault lines, arc crack lines, hilled relief or center collapse crater.

6. Research method

6.1. Overview of research method

The research steps are shown in *Figure 5*. First of all, the authors collected the information of geological conditions, geological structures, lithological composition of rocks, topography, geomorphology, and rainfall. Based on analysis of data collected, the authors conducted field surveys to assess the landslide status in the study area, at the same time to find out traces of the ancient landslide. For next step, the authors analyze the process of sliding and landslide mapping for the study area.

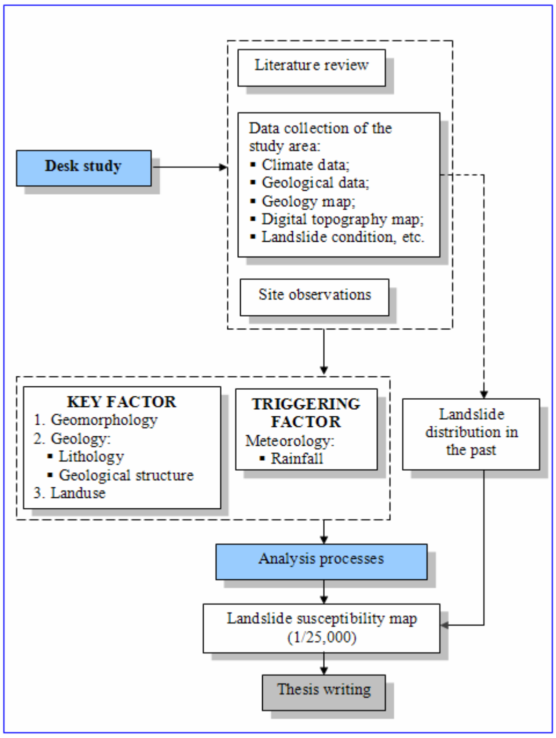

Figure 5. Overview of the research work

6.2. Analysis approach

Factors (data layers), which have been used for the preparation of the landslide susceptibility map were obtained from different sources as *Figure 6*. All the above data layers were converted to raster format in GIS and each representing an independent variable of constructed spatial database. There are two basic approaches for such a study:

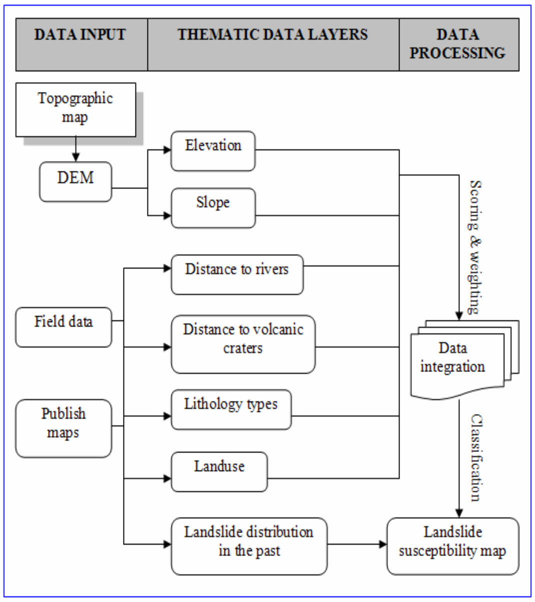

Figure 6. Flow diagram of the analysis methodology

(1) One approach uses statistics to compute the weighting values based on the relationship of the factors with existing landslides. However, if the data set is small and sufficient landslide information is not available, the statistical approach may give erroneous results (Sarkar and Kanungo, 2004).

(2) The other approach is the qualitative map combination where relative weighting values and scoring values are assigned to the factors and their

classes that based on the basic of field knowledge and experience and so on.

In the study area has adopted a technique of qualitative map combination by developing a rating system, which is based on the relative importance of factors influencing slope instability in the study area. This method of qualitative map combination has become very popular in slope instability zonation, but the problem with this method is that the exact weighting of the various parameter maps is often based on insufficient field knowledge of the important factors, which will lead to unacceptable generalizations (Marinos et al., 2001). Establishment of weights for variables was somewhat arbitrary as long as relative rather than absolute landslide susceptibility estimation is attempted. The final weights were adopted after the optimizations of the susceptibility map by repeated examination of the combination of various factors above. The following GIS procedures are used:

- Classification of each data layer (factor) into a number of relevant classes;

- Assignment of scoring values to each of the parameters classes (e.g., on a scale of 1 to 5, giving higher values to more susceptible levels);

- Assignment of weight values to each factor, giving higher values to more influence towards landslide occurrence;

- Calculation of Landslide Potential Index (LPI) to classify susceptibility class and to express the combination of the different weighting layers into a single map using a certain combination rule:

$$LPI = \sum_{i}^{n} (W_i \times S_j)$$

Where: W_i - Weighting of data layers i (n factors = 100%), S_j - scoring of class j (j between 1 and 5) and n - number of data layer.

7. Digital elevation model & its derivatives

Digital Elevation Model (DEM) can be used to derive information on elevation, slope inclination from topographic map was employed for generating the DEM. Contours at 10m intervals were considered for generating the DEM using the Triangulated Irregular Network (TIN) module of ArcGIS 3D Analyst (Figure 2).

- *Slope inclination* has multiple influences on the slide susceptibility. It directly effects on sheer stress in soils-unconsolidated materials - and indirectly controls surface water velocity (degree of saturation). Gentle slope - low gradients are expected to have lowers susceptibility to sliding than steep ones. For the study area, a slope inclination map with a 25m grid cell size was generated from the DEM. The map represents the spatial distribution of slope values in the area. These were classified into five classes as: < 5°, 5 - 15°, 15 - 25°, 25 - 40° and > 40° as *Figure 7* and Elevation as *Figure 8.*

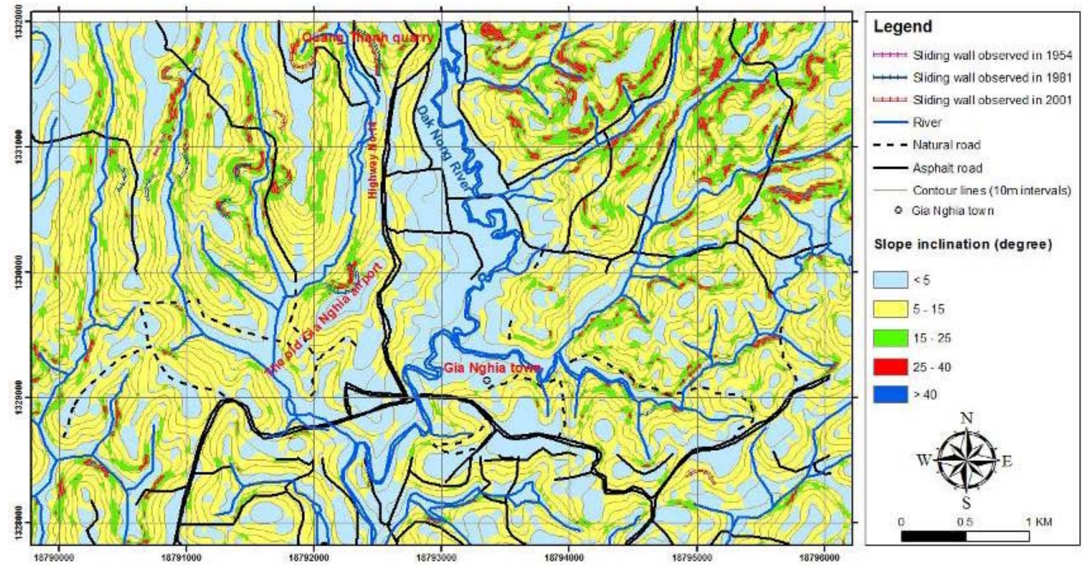

Figure 7. Slope inclination map

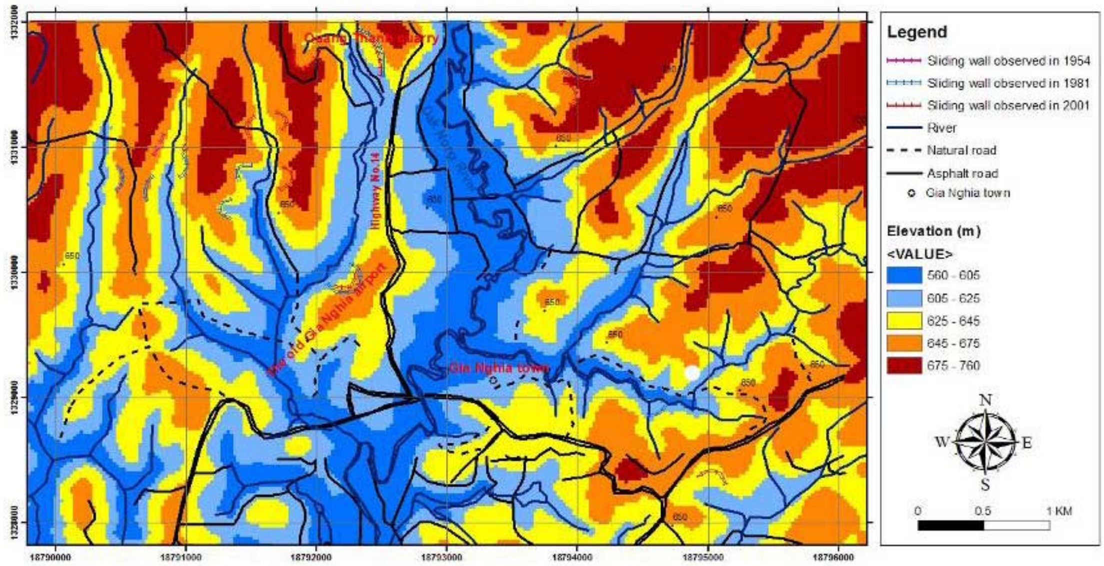

Figure 8. Elevation map

- *Distance to rivers*: proximity to rivers or streams was saturated slope material. Based on the landslide distribution in the past was almost of sliding wall within 0-200m to the river. This distance to the river which soil materials may be more saturated than others area, so this distance is more potential to slide than zones are more than 200m. A distance to river map was calculated as *Figure 9.*

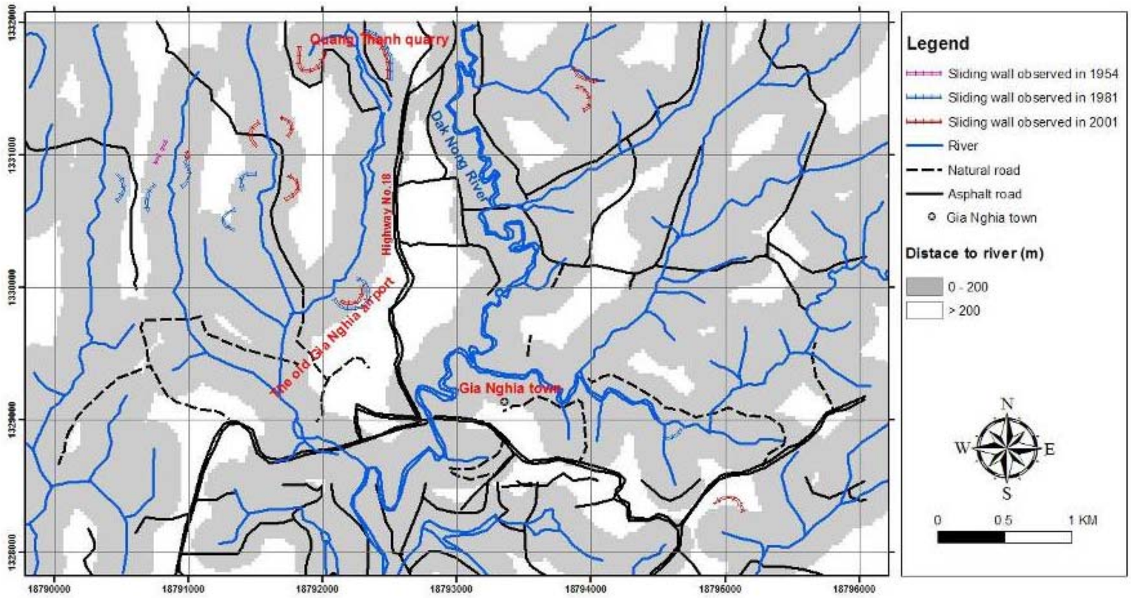

Figure 9. Distance to rivers map

- *Distance to volcanic craters*: Observations of landslide distribution in the past, some landslides occurred on surrounding volcanic crater zones. Many cracks systems were generated, in particular, surrounding volcanic craters; some zones within 0-130m, some zones within 0-170m. Mass of soils/ rocks may be a furious breakdown in these zones. An average of distance was calculated within 0-150m as *Figure 10***.**

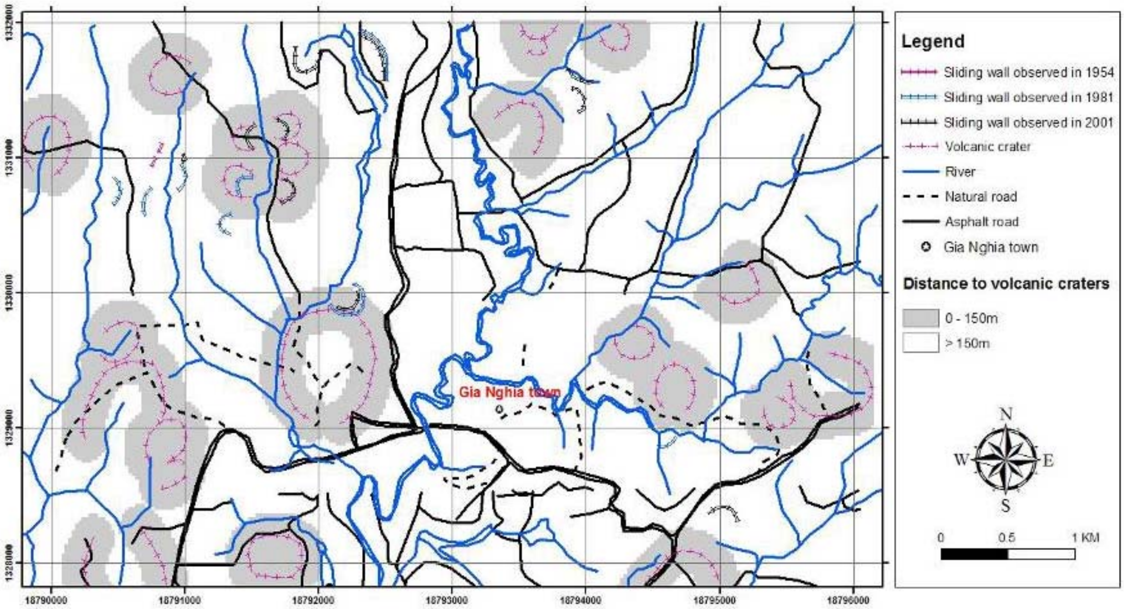

Figure 10. Distance to volcanic craters map

- *Lithology types*: Researchers (Koukis et al., 1994) emphasized on the role of lithology in stability of slopes. Lithology exerts a fundamental control on the geomorphology of a landscape. Based on the geological map, there are four types present in the area. These are cobble - granule - sand sediment (aQ_2), sand - silt - clay sediment (aQ_2^{1-2}), weathering crust of basalt and sandstone - siltstone - clay shale as *Figure 11*.

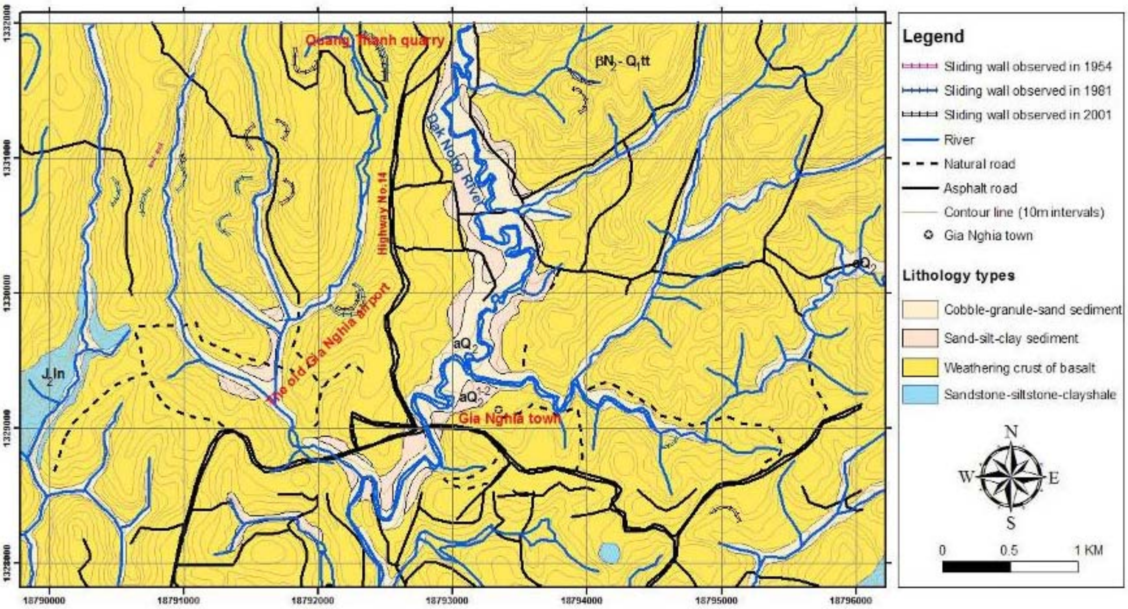

Figure 11. Lithology types map

- A land use map in hilly areas in general shows the distribution of forest cover, water bodies, and types of land use practices, etc. To prepare this map with different land use types of the area based on field observations, data collection of the study area as well as available natural forestation cover map (Vu et al., 2006), in general, relatively, it was observed the area covered by wasteland, sparse forest, plantation area and populated area (*Figure 12*).

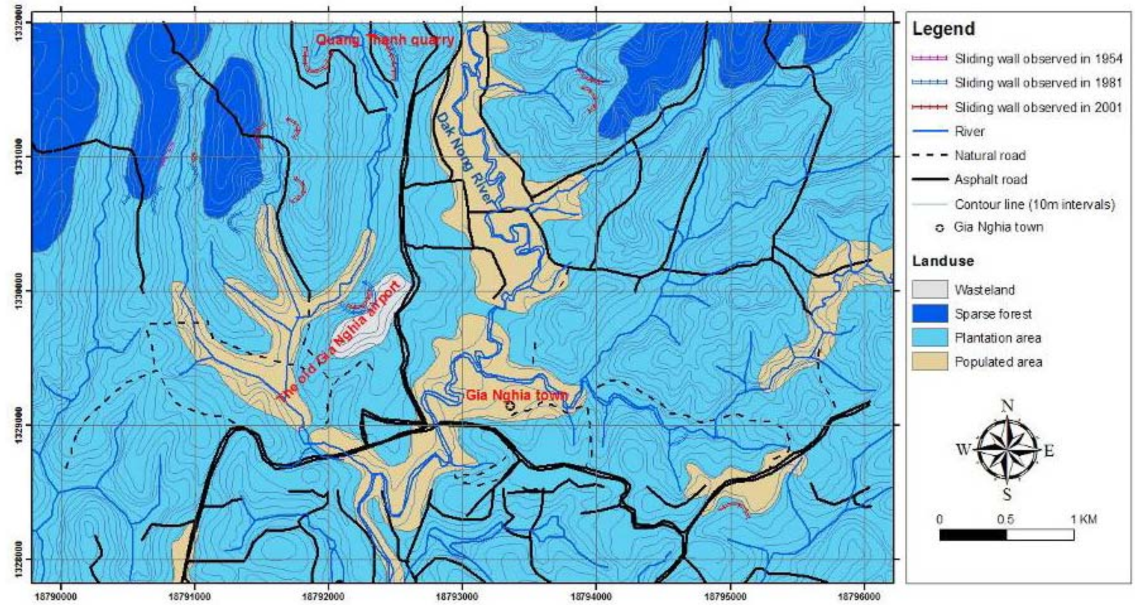

Figure 12. Landuse map

8. Analysis

8.1. Analysis process toward landslide occurrence of factors

Factors	Weighting
Lithology types Slope inclination	Higher
Distance to volcanic craters	↓
Distance to rivers	
Elevation	
Land use	
	Lower

8.2. Analysis of scoring and weighting

Scoring:

There are many ways to give scoring for susceptible levels of classes. For examples, the scale of 1 to 6 used to give scoring values of classes in Yunnan, China (Lan et al., 2004); or the scale of 0 to 9 used to give scoring values in Darjeeling Himalaya, India (Sarkar and Kanungo, 2004); or the scale of 1 to 5 used to give scoring values in Song Be area, Vietnam (Tran and Ha, 2005), etc. In the study area, the topic used scale of 1 to 5 to analyze, where higher value is to more susceptible level and lower value is to less susceptible level as in *Table 1*.

Table 1. Scoring for classes of factors

No	Factors	Classes	Scoring
1	Lithology types	1. Cobble - granule - sand ($aQ_{2)}$	1
		2. Sand - silt - clay sediment (aQ_2^{1-2})	1
		3. Weathering crust of basalt	5
		4. Sandstone - siltstone - clay shale (J_2ln)	3
2	Slope inclination	1. < 5°	1
		2. 5 - 15°	2
		3. 15 - 25°	3
		4. 25 - 40°	4
		5. > 40°	5
3	Distance to volcanic craters	1. 0 - 150m	5
		2. >150m	1
4	Distance to rivers	1. 0 - 200m	5
		2. > 200m	1
5	Elevation	1. 560 - 605m	1
		2. 605 - 625m	2
		3. 625 - 645m	3
		4. 645 - 675m	4
		5. 675 - 760m	5
6	Landuse	1. Wasteland	5
		2. Sparse Forest	3
		3. Plantations	5
		4. Populated area	1

Weighting:

How to define the weighting values for factors in the area? Because the data is limited, a qualitative map combination method is chosen for analysis in the area. As mentioned in above, establishment of weights for variables was somewhat arbitrary as long as relative rather than absolute landslide susceptibility estimation is attempted. Therefore, according to analysis results in above in order to importance of factors, the topic is going to give some cases of weighting in every factor (7 cases), after that comparing to landslide distribution (16 points of landslide distribution) in the past (*Figure 13*) to choose the final weight values. The details is shown bellow:

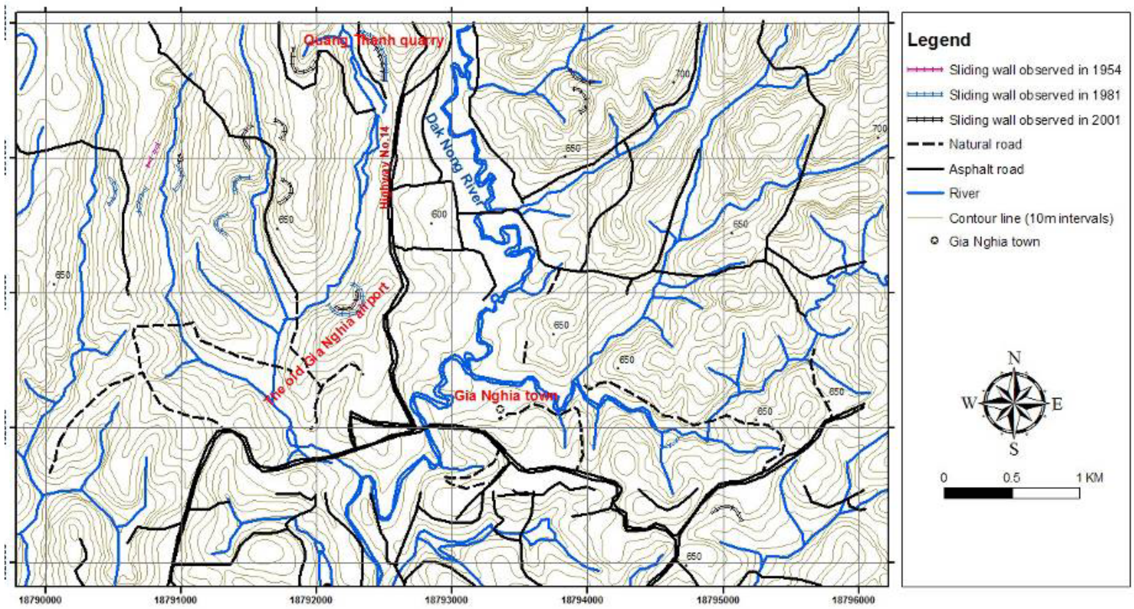

Figure 13. Landslide distribution map (modified after Vu et al., 2006)

Case 1. The weighting values for factors in *Table* 2.

In this *case 1*, there are 11 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 7 with high).

Case 2. The weighting values for factors in Table 2.

In this *case 2*, there are 8 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 4 with high).

Case 3. The weighting values for factors in Table 2.

In this *case 3*, there are 8 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 4 with high).

Case 4. The weighting values for factors in Table 2.

In this *case 4*, there are 8 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 4 with high).

Case 5. The weighting values for factors in Table 2.

In this *case 5*, there are 8 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 4 with high).

Case 6. The weighting values for factors in Table 2.

In this *case 6*, there are 8 points of landslide distribution in the past with high and very high susceptibility classes (4 with very high & 4 with high).

Case 7. The weighting values for factors in Table 2.

In this *case 7*, there are 6 points of landslide distribution in the past with high and very high susceptibility classes (1 with very high & 5 with high).

Table 2. The weighting values for factors

No	Factors	Weighting (%)						
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
1	Lithology	22	20	25	26	27	30	33
2	Slope inclination	20	19	22	23	24	25	30
3	Distance to volcanic craters	18	18	20	21	22	23	20
4	Distance to rivers	16	17	18	13	18	15	10
5	Elevation	15	16	10	10	6	4	4
6	Landuse	9	10	5	7	3	3	3

According to 7 cases as above, comparing to landslide distribution in the past, case 1 is chosen as final result. Bellowing is showed susceptibility classes and Landslide Potential Index (LPI) (*Table 3*) and landslide susceptibility map of the study area (*Figure 14*).

Table 3. Susceptibility classes & LPI

Susceptibility classes	LPI
Very low	1 - 1.925
Low	1.925 - 2.475
Medium	2.475 - 3.039
Hight	3.039 - 3.635
Very hight	3.635 - 5

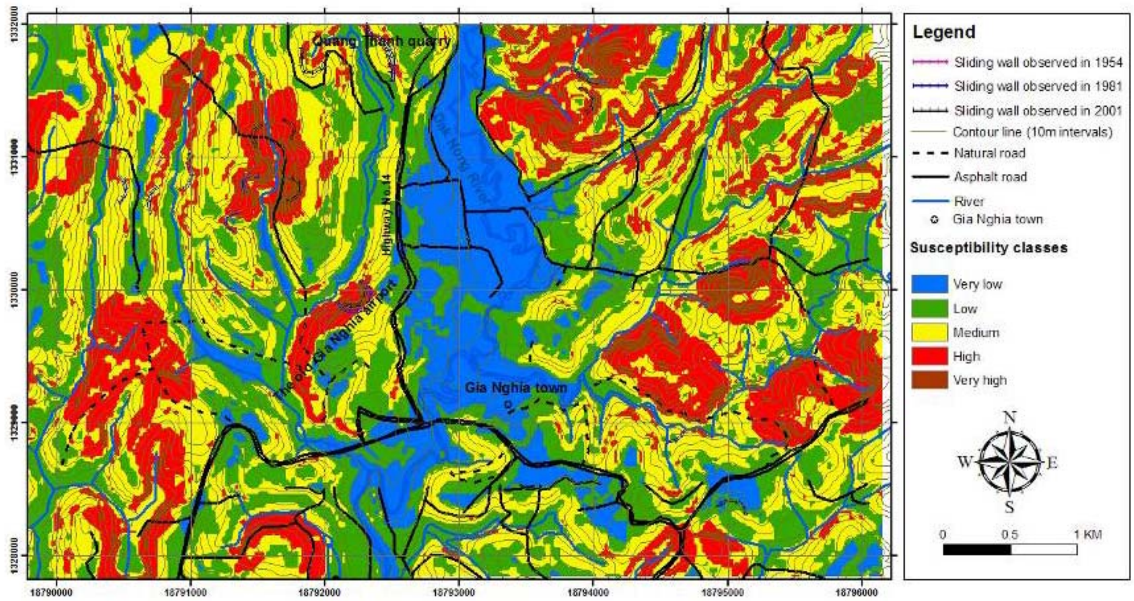

Figure 14. Landslide susceptibility map

9. Characteristics of landslide susceptibility classes and some general suggestion

9.1. High and very high susceptibility classes

Most of distributions of high and very high susceptibility classes occur on weathering crust of basalt, especially surrounding volcanic crater zones, etc. where soil/rock mass is serious breakdown. Most of landslide distribution in the past occurred on these zones. These zones are a good condition to move or concentrate groundwater; weathering crust of basalt is rapid development, etc. Soil materials can be saturated well near the rivers (0 - 200m), the classes of high and very high susceptibility also related to these zones. Beside that, the distributions of these classes are within 5 - 40^0 of slope, a small number of more than 40^0. With the conditions like this, zones of high and very high susceptibility are not only already occurred as in the past, but also having re-sliding capacity in the future.

Some general suggestion for these zones as:

- The government do not build the large projects, the important projects and reducing development of populated area in these zones;

- Don’t program or develop urban areas, populated areas, industrial areas, high-rise building;

- Should be forested; greenery planting and can also exploit groundwater in these zones;

- Should have education programs for community;

- Should have good drainage systems, etc.

9.2. Medium susceptibility class

Medium susceptibility class is distributed surrounding volcanic craters and long - range along to the rivers within 0 - 200m, slope inclination within 5 - 15^0, 15 - 25^0, and a number small of more than 25^0. Some points of landslide distribution in the past occurred on this zone and may be re-sliding again. When land using on this zone need to avoid susceptible zones; especially points of sliding in the past.

9.3. Low and very low susceptibility classes

Low and very low susceptibility classes are distributed flat zones, gentle slope and along to the valleys of rivers, etc. Low and very low susceptibility classes can be interested in infrastructures, industrial zones, and populated area development, urban area development, groundwater exploiting, etc.

10. Conclusions

- According to analysis processes and result in above. The causes have been occurred landslide in the study area which identified the conditions of geomorphology and geology, contributing to landslide occurrence in the study area. These factors are controlling factors which control the slope instability, and if having a triggering factor such as rainfall, landslide will occur.

- A qualitative map combination used to develop landslide susceptibility mapping. This method of qualitative map combination is based on field knowledge of the important factors as well as field experience and so on to give the scoring and weighting systems. There are some difficulties to assess the scoring and weighting for classes and data layers; hence, the topic estimated 7 cases to find weighting limitation values every factors. Landslide susceptibility mapping at 1:25,000-scale was done which based on 6 thematic data layers (factors) such as: slope inclination, elevation, distance to rivers, distance to volcanic craters, lithology types and land use. Landslide susceptibility map delineated the study area into different zones of five relative susceptibility classes: very low, low, medium, high and very high. The result was verified by comparing to landslide distribution in the past. Most of landslide distributions in the past were in high and very high susceptibility classes (about 11/16 points).

- The quality of the susceptibility map can be further improved by incorporating more factors. Further, any change in the natural environment by human interference, such as implementation of development projects, deforestation, etc., or changes climate, may be change the existing landslide susceptibility of the area. Hence, such maps should be updated periodically.

11. Recommendations

One research never proved the perfect result; so many things need to be revised, updated and changed but thinking that it is going to provide some the basic information to next researchers who are interested in doing research in this area. There are some recommendations as following points:

- As mentioned above, the quality of the landslide susceptibility mapping can be further improved by incorporating more factors; hence, such maps should be updated and changed;

- The high and very high susceptibility classes should be avoidable for the projects or suggest the suitability methods to minimize, etc.;

- Needing to have many boreholes, soil parameters as well as filed monitoring which is strongly suggested in order to measure pore water pressure, water table and so on to calculate the safety of factor which may verify the result better.

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SUMMARY

Based on data collection and observation of Gia Nghia area of Dak Nong province, six thematic layers were generated, including: slope inclination, elevation, distance to rivers, distance to volcanic craters, lithology types and land use. By quantitative (qualitative) overlaying these layers, authors made landslide susceptibility map for study area which is divided into different zones of five relative susceptibility classes: very low, low, medium, high and very high susceptibility. The result was verified by comparing to landslide distribution in the past. There are 11/16 points of landslide distribution in the past were in high and very high susceptible classes.

Keywords: Landslide susceptibility, Geographic Information System, factor of safety, qualitative map combination.

TÓM TẮT

Phân tích điều kiện địa chất công trình để xây dựng bản đồ nhạy cảm trượt lở khu vực Gia Nghĩa, tỉnh Đăk Nông, Việt Nam

Trên cơ sở các số liệu thu thập và tài liệu khảo sát thực tế tại khu vực Gia Nghĩa, Đăk Nông, các tác giả đã tạo 6 lớp chuyên đề gồm: góc dốc, cao độ, khoảng cách tới các sông, khoảng cách tới các miệng núi lửa, thạch học và đất. Bằng phương pháp chồng lớp định tính đã thành lập bản đồ nhạy cảm lở đất. Trên bản đồ này đã vạch ra 5 vùng nhạy cảm khác nhau: rất thấp, thấp, vừa phải, cao và rất cao. Kết quả được kiểm chứng bằng cách so sánh với các điểm lở đất trong quá khứ cho thấy có 11/16 điểm trong quá khứ nằm trong vùng nhạy cảm cao và rất cao.