STUDIES ON THE CAUSES OF LANDSLIDES FOR MOUNTAINOUS REGIONS IN CENTRAL REGION OF VIETNAM

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Abstract - Landslide is a complex geo-hazard which impacts on sustainable social-economic development in the mountain area. This phenomenon is a result of a combination of critical natural and artificial conditions of many impact factors such as topographic attribute, infrastructure constructions, geology, land cover, and rainfall. Estimating the contribution weights of these factors plays a significant role in disaster management activities. This study focuses on three provinces which are Hue, Quang Nam and Quang Ngai which are frequently and severely impacted by landslide in the central region of Vietnam. Historical events are investigated by statistical analysis, field survey with supports from GIS to figure out these significant factors to landslide occurring in the study area. The result has illustrated landslide increases, according to the development of human activities and long duration critical rainfall.

Key words - Landslide; Central Coast of Vietnam; Weights; GIS; Causative factors.

1. Introduction

In geomorphology, a "landslide" is the movement of a mass of rock, debris or earth down a slope, under the influence of gravity [1]. Since 1970, many studies have been published with a variety of methods and approaches to deal with this phenomenon. Paola Reichenbach et al (2018) classed 23 landslide impact factors into five groups of causatives which are: geological, hydrological, land cover, morphological and other factors. Nevertheless, the proportion of contribution of the causative factors to landslide occurrence is different depending on spatial, temporal distributions of the event [1, 2, 3, 4, 5]. Recent studies which focus on Asian countries such as China, Taiwan, Korea and Japan indicate that duration and magnitude of rainfall are primary causatives of landslides in mountainous areas [3, 5]. Once, rainfall runoff entering topsoil which surfaces layer with a loose structure in a multi-day period combined with terrain slope would lead to destabilization and landslide in this layer.

The mountainous region in the Central Coast of Vietnam is also under the risks of landslides. This is because the area has a combination of two primary landslide causative factors which are terrain slope and prolonged heavy rain occurs annually due to the effects of monsoon or storms from the East Sea. According to reports of Flood and Storm Committee of Central Coast region, a common point is highlighted that landslide events often occur in the area with terrain slope between 10 to 50 degree associated with occurrences of heavy rain happening in many days.

Due to severe damages caused by landslides to economic, environment and society, evaluating landslide causative factor is necessary and will be a prerequisite for further studies such as: developing hazard maps and early warning methods for landslides for the study area. Studying intensively on landslide becomes more popular since 2010. Most of these studies majorly consider geological hazards and other factors such as terrain slopes, land cover, rainfall and human effect. The study to date has calculated rainfall by using annual mean rainfall [6-9], rather than by extreme precipitation rainfall event. This study evaluates causative factors in mountainous areas of Hue, Quang Nam, Quang Ngai province to figure out their influences on landslides occurrences.

2. Study area

This work focuses on study area located in the central coastal region of Vietnam, with coordinates ($15.33^0 \div 15.74^0$ N, $107.07^0 \div 109.08^0$E), with an area of 21,664 Km^2, see Figure1. The terrain of the area tends to descend from the west to the east. West of the study area is adjacent to Truong Son mountain range with the highest altitude at 2586 m. East of the study area is next to the East Sea.

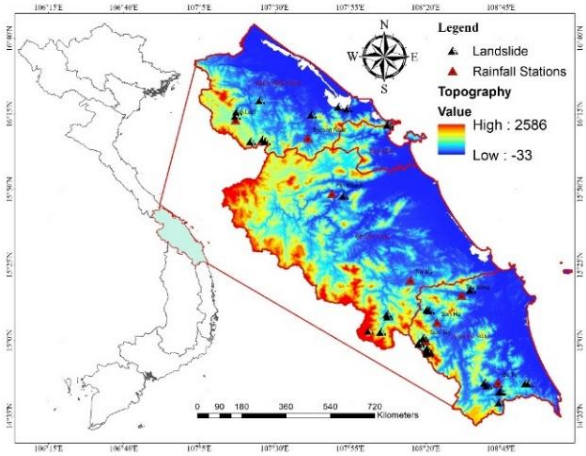


Figure 1. *Study area*

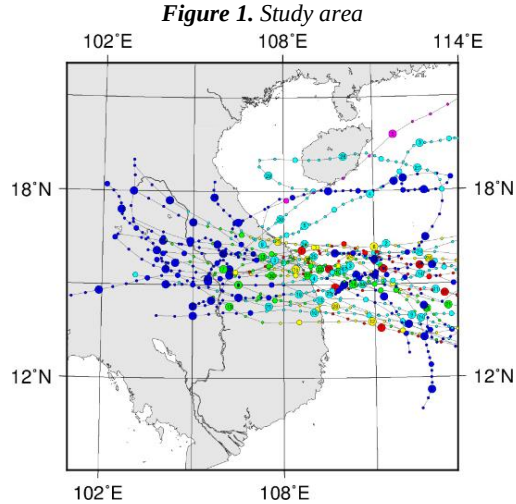


Figure 2. *Landed storm to study area from 1957 to 2018*

Annually, from September to December, the area is hit by an average of 3 to 17 tropical storms along with heavy rainfall into the area, especially in mountainous areas. Figure2 illustrates recorded figures of the trajectory of 27 typical storms in the period from 1957 to 2018, that caused severe flooding and landslides in the study area. This study uses 36 typical landslide points (from 1999 to 2018) to investigate and evaluate the causative of landslides, see Figure1. In addition, Figure 4 shows represent typical landslide that occurred in the study area, taken from field surveying.

3. Material and methods

This study is carried out based on the flowchart which is shown in Figure 3 A number of related data causative factors of landslide including rainfall, terrain data, land cover, soil, stream and road are collected for implementing the study.

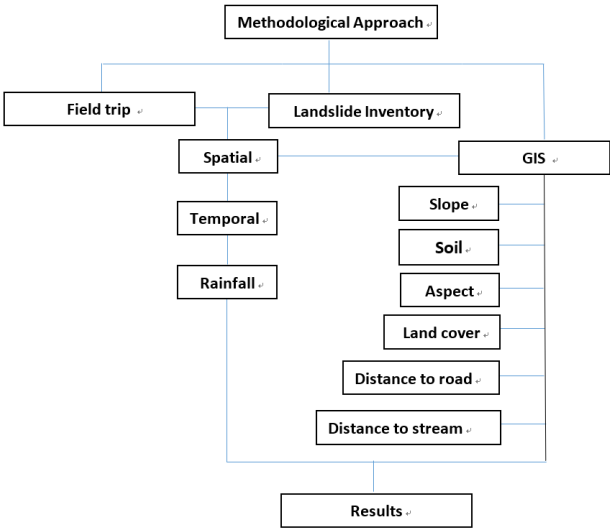


Figure 3. *Flowchart of the methodology adopted for this study*

Rainfall: Based on spatial and temporal distributions of landslides, the correlation between these events and rainfall characteristic such as total rainfall, duration of the nearest stations are investigated, figuring out influences of rainfall to landslides. Rainfall principles such as duration and magnitude, intensities are majorly used in this analyst. Figure 4 show collected rainfall data from the Regional Centre for Hydro-Meteorological (RCHM) in Mid-Central Coast Region of Vietnam.

Terrain slope: The fact that terrain slope is one of the most significant factors in landslide causatives. A review by Reichenbach, Rossi [2] and Naidu, Sajinkumar [3] has confirmed the critical role of slope in instability conditions of the landslide. In this study, terrain slope in the study area is investigated from the STRM DEM (30x30m) using the Arc GIS 10.4.1. Analyzed results are subsequently classified into alternative classes in a range from 10 to 70 degree with 10-degree step.

Terrain aspect: Terrain aspect has a strong interrelationship with land cover, soil strength and moisture intension which directly influence on landslide initiation [4]. Therefore, identifying the correlation between landslide and aspect would assist in projection landslide susceptibility. Aspect data for the study is also created from the DEM.

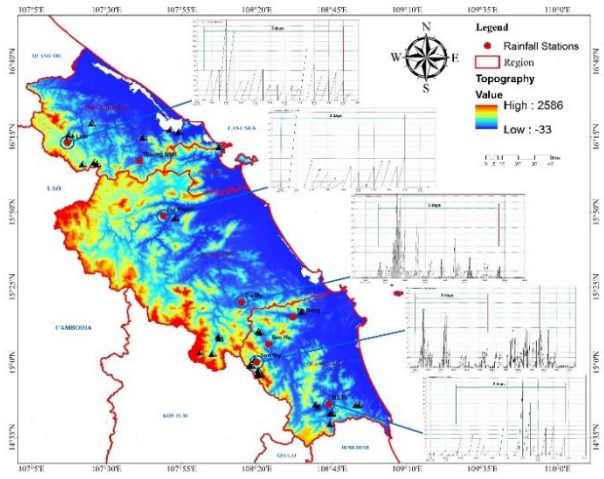


Figure 4. *Rainfall duration corresponding landslide inventory*

Soil: Under response to rainfall, saturation of soil is an important trigger to landslides. Determining soil class and their characteristic makes a huge contribution to landslide and susceptibility assessment. Spatial distributions of soil in study areas are gathered from local authorities and processes in Arc GIS for Thua Thien Hue and Quang Nam provinces while and a hard copy is used for Quang Ngai province.

Landcover: According to Khan, Shafique [4], Land cover has a strong influence on the distribution of landslides. An evidence that good vegetation cover would work effectively to retain water generation, reduce erosion and then improve the stability of the area [5]. In a recent study, Reichenbach, Rossi [2] have suggested an equal contribution weight to landslide between land cover and precipitation. So, the study also uses provided data from local environmental authorities to examine the relationship between soil distribution and landslide events.

***Distance to roads*:** In mountainous areas, the development of transportation is more likely to lead to vitiating slope and reducing the stability of slope and eventually landslide. Therefore, the impacts of road network need to be evaluated in landslide inventory. A database of the road networks collected from local government is used in this report

Distance to stream: Similarly, distance to stream is also a popular causative, which is popularly used in landslide analyzing. The spatial distribution of the factors is evaluated in a GIS environment by using either DEM analysis or obtained data from authorities [10]. In this study, the factors are linearly calculated using basic spatial operations from data collection.

Collected data, which is related to causative factors of landslides, and their quality, standard and sources are represented in Table 1.

Table 1. *Data collection for Landslide inventory*

Causative factors	Spatial distribution/quality	Data type	Supplier/sources
Rainfall	Rainfall stations, hourly rainfall data	Hard copy	RCHM central coast region
DEM	30x30 m STRM DEM	STRM Dem	

Soil	Hue Province 1:100,000 Quang Ngai 1:100,000 Quang Nam1:25,000	ESRI shapefile	Departments of Natural resource and environment. (Hard copy for Quang Ngai province)
Land use	Hue:1:100,000 Quang Nam 1:25,000 Quang Ngai 1:25,000	ESRI shape file	Departments of Natural resource and environment.
Road	National road, provincial road and all district road (1:25,000)	ESRI shape file	Departments of Natural resource and environment.
Stream	River, spring and stream flow regularly 1:25,000	ESRI shape file	Departments of Natural resource and environment.

4. Result and discussion

Statistic evaluated results of rainfall data at selected stations and long rainfall duration are more likely to significantly impact on landslide occurrences in the study area, see Figure 5, in which, a huge proportion of landslide correlates with 3-day antecedent rainfall, accounting for 72% of recorded data. The second largest figure for impacts of rainfall patent falls into 5-day antecedent rainfall with a percentage of only 16% in 36 points. Therefore, 3-day antecedent rainfall is suggested for use in further landslide related analysis in the regions.

Table 2. *Total rainfall in landslides zone*

Value	Total rainfall amount (mm)		
	Zone 1	Zone 2	Zone 3
Duration	5-day antecedent rainfall	3-day antecedent rainfall	3-day antecedent rainfall
Minimum	1194	78	546
Average	1780.4	369.8	734.4
Maximum	2269	915	915

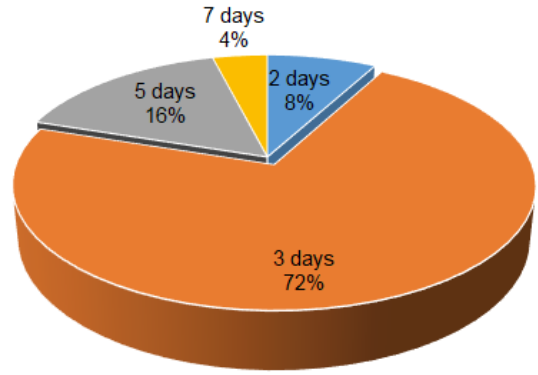
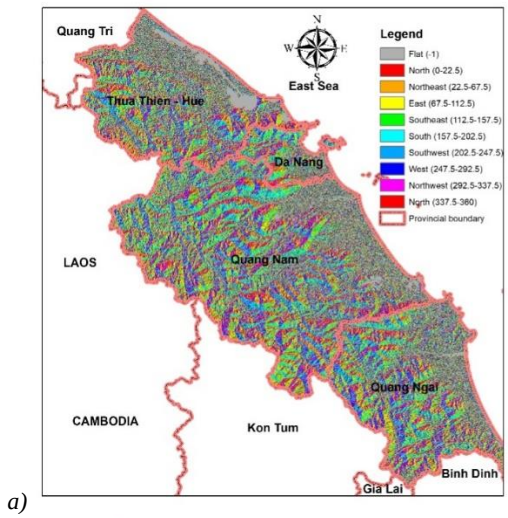
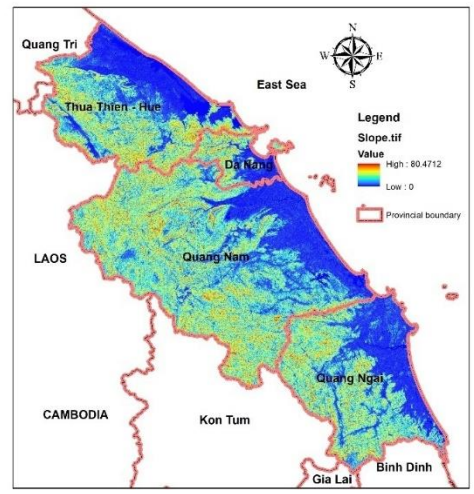


Figure 5. *Proportions of rainfall duration correlated to landslide inventory*



a)



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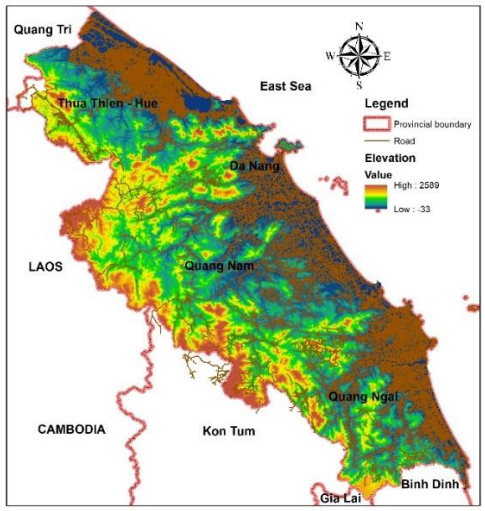

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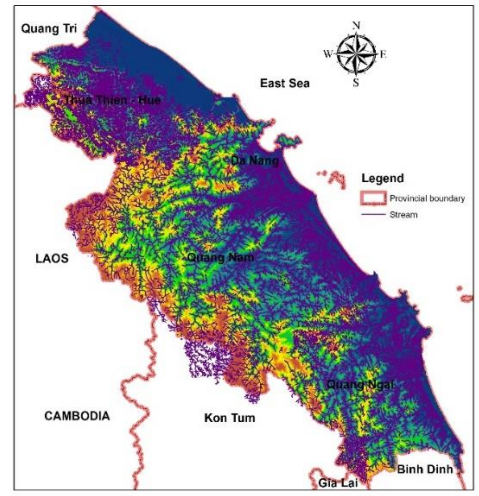

d)

Figure 6. *Landslide causative factors used in the study. (a) terrain aspect (b) Terrain slope (c) distance to road (d) distance to stream*

Based on the spatial distribution of landslide in the study area, the landslide points are grouped into 3 sub-regions. The activity would effectively highlight rainfall characteristic contributes to landslide-prone in the area. Statistical features of rainfall for three regions: Zone 1 (Thua Thien Hue Province), Zone 2 (around Quang Nam and Quang Ngai Border area), and Zone 3 (Ba To district of Quang Ngai Province). Table 2 represents the total amount of rainfall observed during landslides occurrence.

The other causative factors of landslide such as terrain slope, terrain aspect, distance to the road, distance to stream, land use and soil are analysed in Arc GIS version 9.4.1 and related statistic tool. The result of spatial analysis in Arc GIS is represented in Figure 6. In addition, the relationship of these causative factors and landslide is shown in Figure 7.

The study result finds an agreement with rainfall characteristic and spatial distribution of landslides that occurred in the study area. Due to terrain characteristic, appearances of prevailing windward aspects such as Hai Van, Ngoc Linh, and Ba To mountains which are perpendicular to Truong Son mountain range, these areas are more vulnerable with monsoon, storm and tropical depression. As a consequence, heavy rain which prolonged from three to five days often occurred.

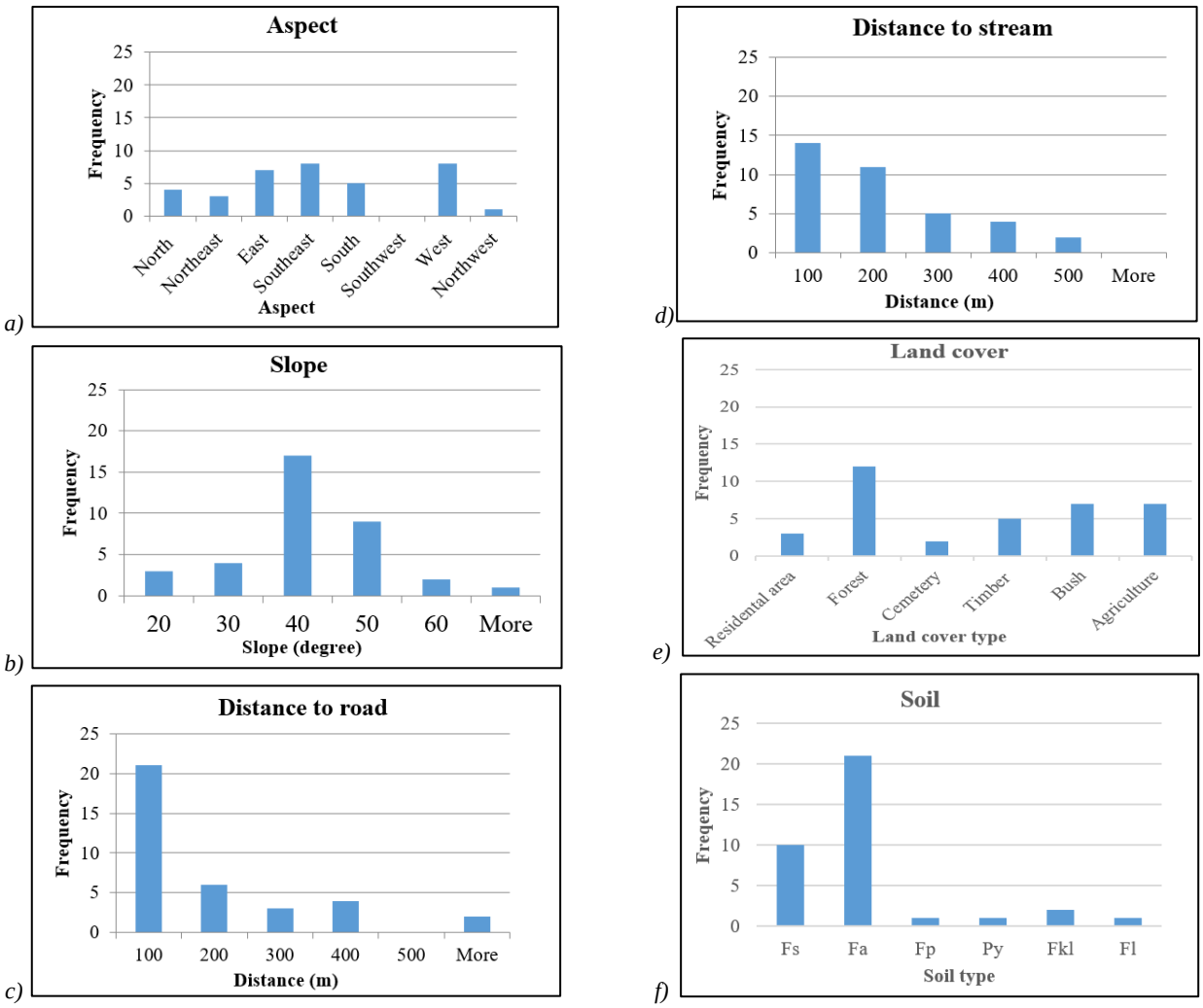

Figure 7. *Relationship of occurred landslides with causative factors. (a)terrain aspect, (b) terrain slope, (c) distance to road, (d) distance to stream, (e) land cover (f) soil layer*[*]

[*]*(Fs) Shale-based Ferralic Acrisols, (Fa) Acid Magma based Ferralic Acrisols (Fp) Fluvisol based Ferralic Acrisols (Py) Fluvisol, (FKL) Base and neutral Magma based Ferralic Acrisols, (Fl) Plinthic Acrisols)*

The terrain with slope gradient from 30 to 40 degree is the most landslide prone which accounted for nearly a half of happened events. The occurrences of landslide increase with an increase in slope of terrain in rain from 10 to 40 degree. In contrast, there is a decrease in the figure for a range of slope higher than 40 degrees. In terms of aspect criteria, landslides are more likely to happen with terrain aspect related to East direction (Southeast, East and Northeast), accounting for 50% of evaluated landslides.

Landslide inventory and GIS analyst have shown strong correlation with the phenomena with distance to transportation systems and stream system. A large proportion of landslide happen areas where close to road and stream. Nearly 60 per cent of landslide happened in the buffer area of 100 meters from the roads. The influences of the roads on landslide phenomena decrease sharply with the increase of the distance. Regarding stream, the same figure is also seen at distance to stream. The highest

percentage of landslides falls into the closest area to stream with 100 m buffer distance.

Historical landslide analysis represents a strong influence of soil layer on the stability of prone. Most of the landslides occurred on Ferralic Acrisols in the study area with over 80 per cent. However, there are differences in spatial distributions of the soil type between these areas. While the phenomena majorly occurred on Shale based Ferralic Acrisols (Fs), the figure for Quang Ngai and Quang Nam primary on Acid Magma based Ferralic Acrisols (Fa).

Although spatial distribution of landslide showed the highest record for forest land cover, the percentage of land cover which is affected by human activities dominates the occurred statistic. Together with bust and agriculture area which account for second highest frequencies of landslides at 7 places each, timber residential area and cemetery take a part of two-thirds in total landslide events.

There is a distinction of in the cases of multi-causative factor evaluation in landslides in the area. in specific, Landslides that occurred in Thua Thien – Hue Province occurred under influences of 5-day extreme precipitation with an amount of over 1000 mm. Landslides occurred in the other area with shorter rainfall duration (3-days) and much smaller with a maximum amount just 737 mm. The difference can be explained by analysing soil layer in landslide points. Due to cover on Acid Magma based Ferralic Acrisols (Fa) which are much weaker than Shale based Ferralic Acrisols (Fs), landslides are more likely to occur with shorter and smaller rainfall compared to Hue Province.

The development activities in mountain area significantly increase landslide occurrence. Perhaps, the most obvious evidence is the figure of road construction influence on landslide-prone with nearly two-third events that occur in a buffer area of 100 m from the road. The influences of human activities are also marked in changing the land cover. Recently, forest areas have fewer landslide than other considered land covers such as agriculture and residential area.

Although some limitations still exist in the procedure such as lack of adequate database or skills workers to carry out the process, GIS and its statistic tools can be effectively used in evaluation and inventory landslide causative factors. The tool can demonstrate spatial distributions of landslide causative factors which can be useful for extracting required data for landslide susceptibility procedure.

5. Conclusion

The study has investigated landslide causative using statistic, field survey and GIS processing and stated different influences of causatives factors on landslide inventory from 1999 to 2018. While terrain slope, aspect, distance to road or stream find agreement with impact on landslides, rainfall and soil demonstrate different impact among distinct zones. The study also highlights the impacts of human activities on landslides. Changing in land cover and development of infrastructure increase instability in mountainous areas in this region. Overall, this study has successfully examined major impact factors on landslide based on statistic, field survey and GIS processing. The result can play a significant role in developing landslide susceptibility for this area.

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