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GIS – Remote sensing application of landslide hazard mapping - Case study Thua-Thien-Hue Province, Vietnam

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ABSTRACT: Landslides are the result of processes, which include geological, geomorphological and meteorological factors. The most important factors are lithology, structure, drainage, slope, land-cover, and geomorphology. In order to make a landslide hazard map, all these factors need to be analysed in order to define the instability in a region. Remotely sensed data provide valuable information for determining the occurrence of landslides, such as recent land-cover and fractured zones.

- The method of landslide hazard analysis, which is applied in the Thua-Thien-Hue Province (TTH), is based on the methodology of Chung and Shaw (2000) with the following assumptions: Future landslides will occur under circumstances similar to the ones of past landslides in either the study area or in areas in which experts have obtained their knowledge on the relationships between the causal factors and the occurrences of the landslides.
- Spatial GIS data representing the causal factors can be used to formulate the future landslide hazard.

Data integration was carried out using the ordinal scale (qualitative) relative weighting rating technique to give a Landslide Hazard Index (LHI) value. The breaks in the LHI frequency diagram were used to delineate various landslide hazard zones, namely, very low, low, moderate, high and very high. Field data on landslides were employed to evaluate and validate landslide hazard zonation map (Saha, 2002).

This paper describes the methodology used and the generation of seven thematic layers: 1) recent land cover; 2) geological fracture zone map; 3) weathering rock map; 4) geotechnical map; 5) geomorphological map; 6) slope map and 7) DEM.

It is shown that the potential landslide hazard map can be established by statistical correlation of landslide frequency with these seven factors. The applicability of the map is shown by the fact that the Vietnamese government and NGO-projects take account of the results for their development planning in TTH.

1 INTRODUCTION

The objective of this study is to investigate a methodology for creating a landslide hazard zonation map on a medium scale. Landslide Hazard Zonation (LHZ) is a process of ranking different parts of an area according to the degrees of actual or potential hazard from landslides (Varnes, 1984). In hazard studies GIS is often used to qualitatively determine the zones of landslide hazard and to combine, manipulate and analyse data layers (Saha et al., 2002; de Vleeschauwer and De Smedt, 2002; Nagarajan et al., 1998). Some of these data layers are DEM, slope, aspect, altitude, lineaments, precipitation, lithology, etc. Also the application of RS is very appropriate in providing a land-use map. For a natural resources expert GIS and RS function therefore as an instrument to assess landslide hazards more efficiently and economically.

A two-dimensional, raster based, GIS model is developed in ILWIS 3.0. The result of the landslide hazard zonation is obtained by using a series of digital maps with a pixel resolution of 30 m.

2 METHODOLOGY

The following digital data to zone the landslide hazard on a medium scale is used:

1) recent land cover, which is based on a classification of remote sensing data
2) geological fracture zone map, which is created from lineaments
3) weathering rock map
4) geotechnical map
5) geomorphological map
6) slope map and
7) DEM.

LHZ methods for data integration and interpretation have been summarized and discussed by van Westen (1994). The three main types of methods are:

(1) landslide distribution analysis, which provides information on the distribution of landslides in an area;
(2) the ordinal scale (quantitative) approach using weighting–rating system of various parameters, which is based on field observation and
(3) the statistical method, which is suited to small areas with detailed surveying.

In this study, the medium scale, qualitative, landslide hazard analysis using relative weights has been used to develop a landslide hazard zonation map. Key areas are selected to determine the relative weights. These weights are used to establish a landslide hazard index (LHI) for the whole area. The breaks in the LHI frequency diagram are used to delineate the landslide hazard zones: very low, low, moderate, high and very high.

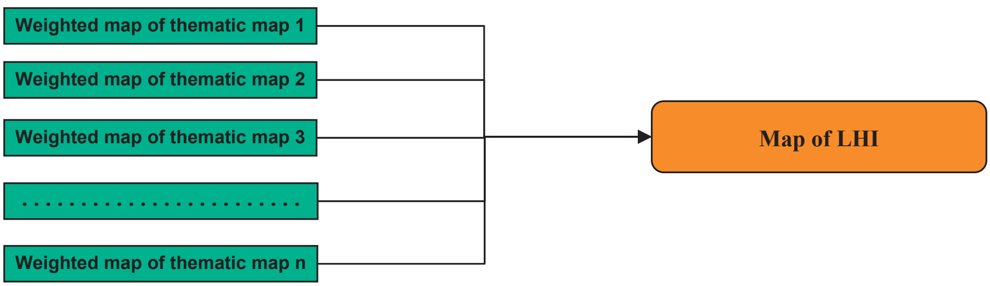

Figure 1. The model for LHI calculation.

The LHI for each key area is defined on basis of the equation:

$$LHI = \sum_{j=1}^{n} w_j x_{ij}$$

where:

LHI is the landslide hazards index
wj is the weight of factor j (thematic map numbered j)
xij is the weight of element i in the factor j

The xij weight is determined based on the frequency of occurrence of landslides in class i of factor j. The wj is calculated as the standard deviation of the xij weight in the factor j.

Figure 2. The study area

3 RESULT AND DISCUSSION

The Thua-Thien-Hue (TTH) province is located in the central part of Vietnam (Fig. 2), covering approximately 5000 km2 and has more than 1 million inhabitants. 70% of the area of TTH is mountainous, while the remaining area consists of a coastal river delta. There is no buffer zone between the mountain and delta area. In TTH province every year, during the rainy season, natural hazards, such as floods and landslides destroy infrastructure and properties, and directly threaten the life of the inhabitants.

Based on the DEM, which is created by manually digitizing the contours of the topographic map, scale 1:50.000, and consequent interpolation of the contours and rasterization with a pixel resolution of 30 m, the slope and relative height map is created. The area descends from approximately 1100 m in the west to 0 m in the east (sea border). The large mountainous part of the study area has a slope of more than 10 degrees.

The geomorphological map, geo-engineering map, and weathering rock map are provided by the Vietnamese government. In each map, the classes are divided based on the soil and rock characteristics.

The fractured rock map is created on the basis of a photo-lineament density index. Photo-lineaments are captured from a Landsat ETM image. The fractured rock map is divided into three classes, indicating the level of fracturing (strong, moderate, and weak).

The landcover map is created on the basis of the vegetation index (VI) and normalized difference vegetation index (NDVI) from the Landsat ETM image and divided into four classes, based on the density of vegetation.

The occurrence of landslides is determined from a field trip. In the key areas, not only field trips but also aerial photos supported the recognition of the occurrence of landslides. Figures 3, 4, 5, 6, 7, 8, 9 are created from the field data obtained from the key areas and indicate respectively the x_{ij} weights: geomorphology, geomechanical characteristics, slope, land-cover, relative height, weathering rock and fractured rock. The determined x_{ij} weights are applied to the whole study area and are used to determine the w_j.

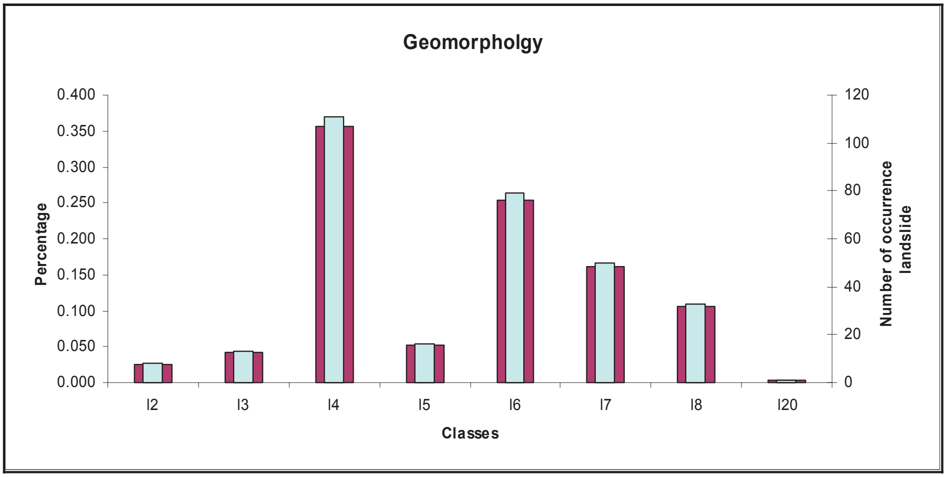

Figure 3. Frequency of occurrence of landslides in % for each class in the geomorphological map

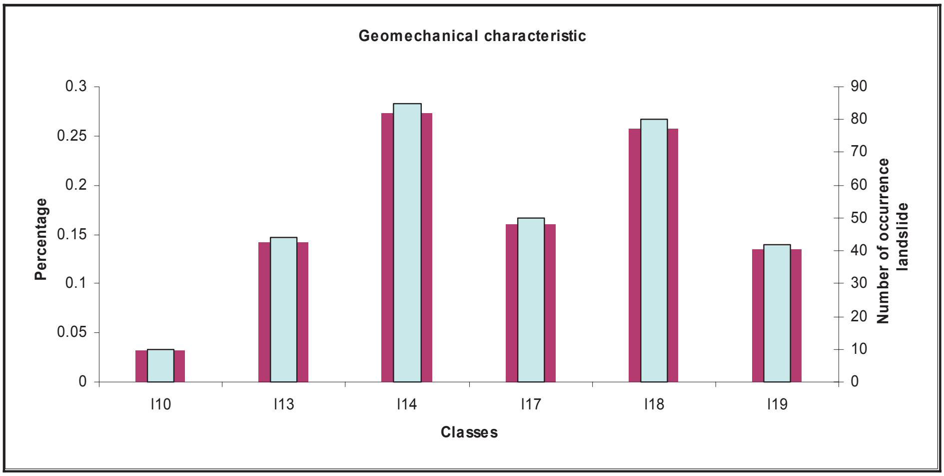

Figure 4. Frequency of occurrence of landslides in % for each class in the geotechnical map

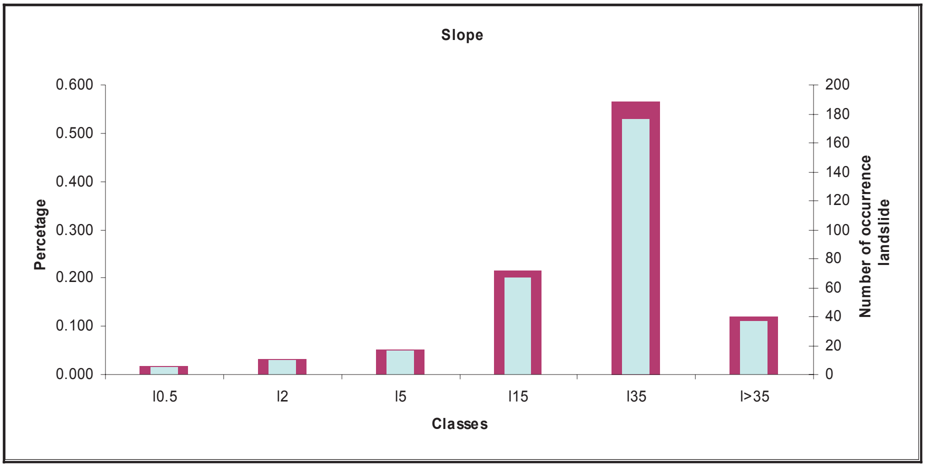

Figure 5. Frequency of occurrence of landslides in % for each class in the slope map

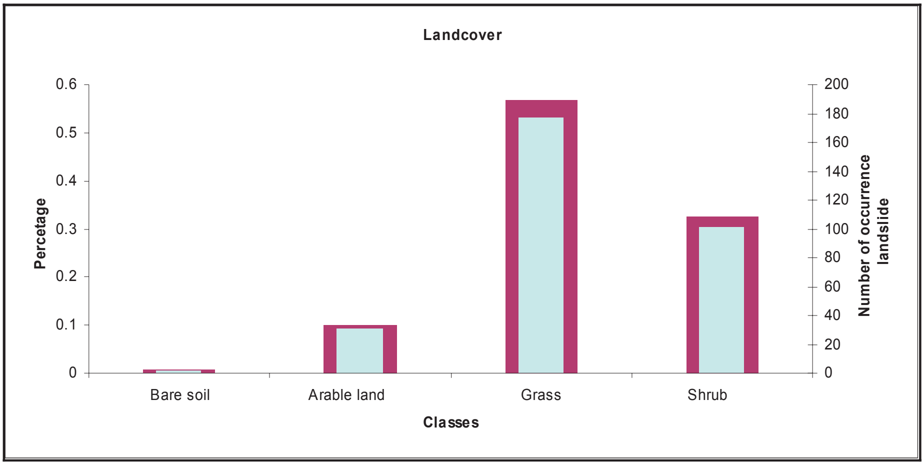

Figure 6. Frequency of occurrence of landslides in % for each class in the landcover map

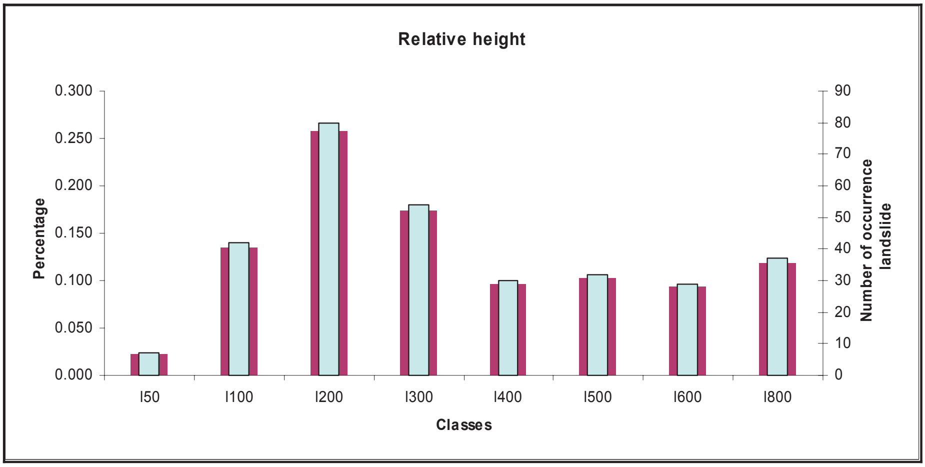

Figure 7. Frequency of occurrence of landslides in % for each class in the relative height map

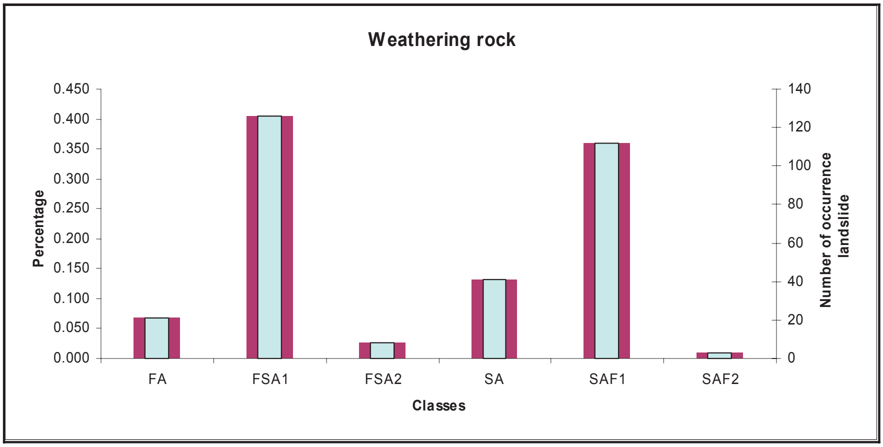

Figure 8. Frequency of occurrence of landslides in % for each class in the weathering rock map

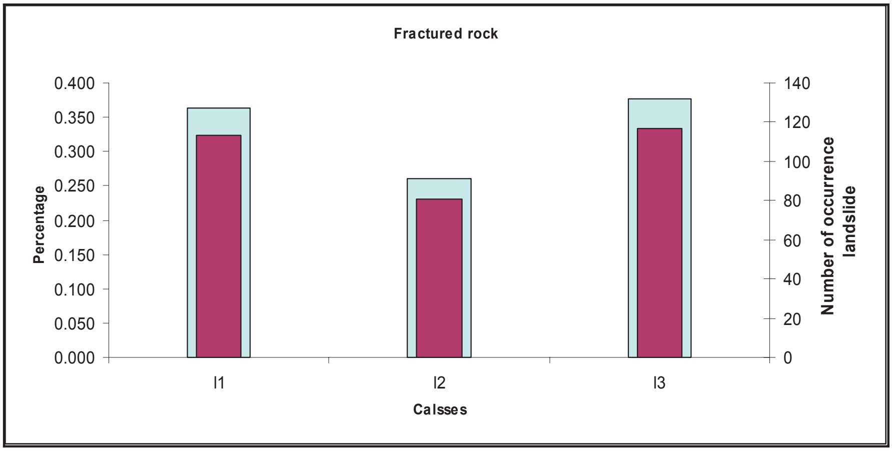

Figure 9. Frequency of occurrence of landslides in % for each class in the fractured map

The weights, wj, are given in Table 1, slope and landcover appear to be the most important factors for landslide development.

Table 1. The weights of each factor

	Relative height	Slope	Geomorphological characteristics	Geo-engineering characteristics	Weathering rock	Fractured zone	Vegetation
w_j	0.07	**0.21**	0.13	0.09	0.18	0.06	**0.26**

Figures 10 and 11 compare the percent area and percent occurrence of landslides for each LHZ class. The 'very high zone' covers only about 17.1% of the total area but has a very high (30.5%) frequency of landslide occurrence. Furthermore, the landslide frequency in the 'high zone' is also high (49.9%) in comparison to the area (42.7%). These two zones cover 59.9% of the area and include 80.4% of the landslide occurrences. The medium hazard zone covers 16.6% of the area and contains only 13.3% of the landslides. The low and very low hazard zones together constitute 23.5% of the study area and have a landslide occurrence of 6.4%. It is recognized that the landslides in the moderate hazard and low hazard zones are more likely to be caused by local effects, i.e. of the orientation of discontinuity surfaces, etc. which could not be incorporated into the GIS analysis.

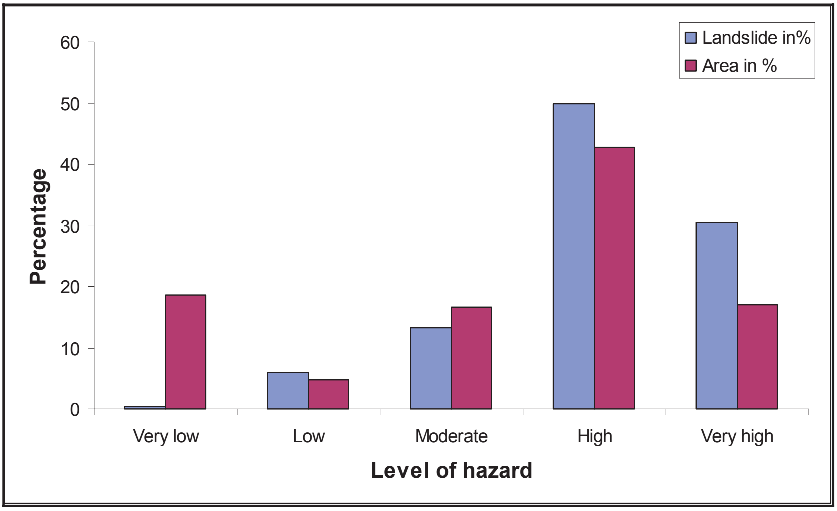

Figure 10. The relative distribution of landslide hazard zones and landslide occurrence within each zone

4 CONCLUSIONS

It can be concluded that the distribution of landslides is largely controlled by a combination of geo-environmental conditions, such as slope, less-vegetated areas, or weathering rock. This is apparent in the buffer zone where an increased slope and lower density of vegetation, increases the potential of landslide occurrence. It is concluded that the presence of a combination of geo-environmental conditions lead to landslide susceptibility of the terrain, local discontinuity surfaces provide the triggering action and pathways for the landslide activity to occur. The remotely sensed data provide useful geo-environmental information, such as recent landcover, fractured zone, etc., that can be used to predict landslide occurrence. The GIS-remote sensing based methodology integrates different information layers and appears suitable for developing a landslide hazard zonation map.

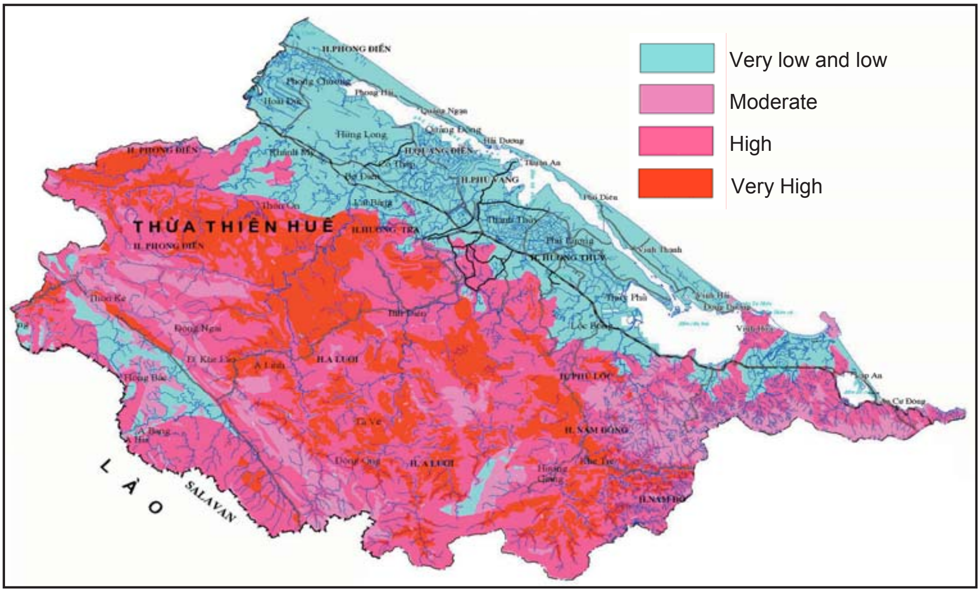

Figure 11. The landslide hazard zonation map of TTH

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