Guidelines for the generation of 1:50.000 scale landslide inventory, susceptibility maps, and qualitative risk maps, illustrated with case studies of the provinces Thanh Hoa and Nghe An

Draft version

November 2013

Dr. Cees van Westen

Faculty of Geoinformation Science and Earth Observation

University of Twente

c.j.vanwesten@utwente.nl

Bộ Tài nguyên và Môi trường

(Ministry of Natural Resources and Environment)

Viện Khoa học Địa chất và Khoáng sản

(Vietnam Institute of Geociences and Mineral Resources (VIGMR)

GeoMapa GIS/Cartography

ITC UNIVERSITY OF TWENTE.

(Faculty of Geo-Information and Earth Obeservation, University of Twente)

Table of Contents

1. Introduction

These draft guidelines are the result of a number of interactions between Vietnamese staff of VIGMR and ITC as part of the Technical assistance for the execution of the project "Investigation, assessment and warning zonation for landslides in the mountainous regions of Vietnam". This Agreement falls under the Decision number 351/QD-TTg of 27 March 2012 by the Prime Minister of the Socialist Republic of Vietnam for approval of the project "Investigation, assessment and warning zonation of landslides in the mountainous regions of Vietnam" to be carried out by the Vietnamese Institute of Geosciences and Mineral Resources, and under the Budget approval decision number 1409/QD-BTNMT by the Ministry of Natural Resources and Environment on 29 August 2012.

ITC and VIGMR collaboration under this Agreement aims to expand knowledge to achieve high results in the investigation, assessment and warning zonation of landslides in the mountainous regions of Vietnam in the following directions:

- Technical assistance and advisory services in scientific research: Participate in workshops and field visit, act as expert advisors to the VIGMR project team in the development of technical guidelines, set-up of a national Spatial Data Infrastructure and Web-GIS related to landslides, and the development of implementation guidelines for landslide risk management at different levels;

- Deliver tailor-made trainings to VIGMR's staffs in Vietnam and The Netherlands: Deliver short courses related to landslide issues to VIGMR's key staff, with specialized courses for the Phase I (2013-2015);

- Liaise with other international experts which will be involved in the planned activities and introduce key Vietnamese project staff to ITC's international network of landslide experts;

In the beginning of the project it is very important to start developing guidelines on the various components of the project, such as:

1. Guidelines for landslide inventory mapping (use of image interpretation, historical archives, existing maps, image processing, event-based inventory mapping, way of mapping, attributes related to typology, activity, date, damage, materials etc.).
2. Guidelines for landslide susceptibility assessment in natural terrains (spatial data requirements and specifications of required data for the two mapping scales of 1:50,000 and 1:10,000, proposed methodologies: for 1:50,000 scale following a statistical approach and for 1:10,000 a dynamic modelling approach including both initiation and runout modelling).
3. Guidelines for landslide susceptibility assessment along cutslopes (characterization of weathering state and development of weathering over time, classification system for landslide susceptibility of cut-slopes)
4. Guidelines for rainfall & landslide correlations and establishment of early warning (as a basis for both temporal probability assessment at 1:50,000 scale and for the generation of rainfall thresholds for early warning at 1:10,000 scale, analysis of existing meteorological data, planning of new meteorological stations, use of synoptic weather data)
5. Guidelines for landslide risk assessment (using a qualitative spatial multi-criteria index approach at 1:50,000 scale and a (semi) quantitative approach at the 1:10,000 scale. Elements-at-risk characterization, exposure analysis, vulnerability assessment)

This document combines the first two type of guidelines mentioned above and focuses the generation of 1:50.000 scale landslide inventory, susceptibility maps, and qualitative risk maps, illustrated with case studies of the provinces Thanh Hoa and Nghe An.

The work is based on a 6 weeks training for 3 VIGMR staff (Mr. Binh, Mr. Thanh and Mr. Hien) from 9 September to 18 October 2013. During this period they focused on the following aspects

- Selection of 3 maps sheets for the work
- Basic photointerpretation method
- Digital stereo image interpretation from airphotos and Google Earth image.
- Generation of landslide inventory consisting of point and polygon data combined with attributes
- Preparation of the input maps for susceptibility assessment
- Initiation susceptibility analysis:
- Bi-variate statistical analysis
- Spatial Multi-Criteria Evaluation
- Generation of initiation susceptibility map
- Validation of the susceptibility map.
- Generating regional scale runout maps using FLOW-R software
- Generating the final susceptibility map
- Combination with elements at risk maps
- Generating qualitative risk maps.
- Cartographic map production
- Generating the final maps

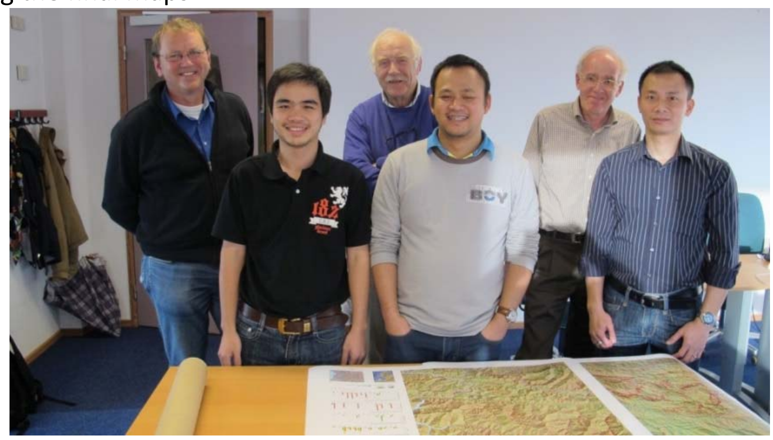


Figure 1.1: The team that worked on the landslide susceptibility maps in ITC.

This report gives a review of the methodology used for the generation of the three test maps, and the aspects that need to be improved in order to come to an optimal method for landslide susceptibility mapping at scale 1:50.000 for many other parts of the country. The report starts with a description of the basic data requirements, and follows with the landslide inventory mapping, the susceptibility assessment approach, and the cartographic representation. The last chapter deals with proposed workflow and time planning.

2. Basic Data requirements

For the landslide susceptibility mapping at scale 1:50.000 the factors that are considered to contribute to landslide occurrence should be mapped. These may differ from area to area, but the most important ones area:

- Topographic layers:
  - Digital Elevation Model
  - Altitude zones.
  - Slope steepness
  - Slope aspect
  - Slope length
  - Upslope contributing area
- Drainage related factors
  - Eroding sections of main rivers
  - Closeness to eroding streams
  - Distance from stream initiation
- Geological layers
  - Lithological map
  - Soil type map
  - Fault map
- Land cover related layers
  - Land cover (existing)
  - Land cover (10 years ago)
  - Land cover changes
  - Road cuts
  - Buildings with cutslopes
- Layers related to triggering factors
  - Spatial distribution of maximum daily rainfall
  - Earthquake Peak ground acceleration map (only in seismically prone areas)
- Landslides
  - Older landslides mapping through image interpretation
  - Recent historical landslides checked in the field.

Not all these data layers are equally important, and they also vary a lot for area to area. However, based on the experience of landslides in Vietnam and the availability of information the list indicated in table 2.1 can be used as guideline. There are also data layers that are very important for landslide susceptibility assessment which cannot be collected at a scale of 1:50.000 for the entire country. The most important one is related to the soil depth, which is a very important factor controlling both slope hydrology and slope stability. The generation of a soil map for a small area is already quite complicated, and it is virtually impossible to generate such maps as standard input layers for 1:50.000 at a level of detail that is still useful for the analysis. Therefore a soil map is not part of the required input data layers indicated in the table.

In the following sections a review will be given of the data layers, and for each data layer also the method for generation will be explained. Also a review is given of the available data layers for the 3 maps sheets used in the test phase of this project.

Group	Factor	Importance for susceptibility assessment	Used in 3 test sheets	
			Available	Quality of data
Topographic factors	Digital Elevation Model			
	Altitude zones	Moderate	Not used	
	Slope steepness	High	Yes	Good
	Slope aspect	Moderate	Not used	-
	Slope length	Moderate	Not used	-
	Upslope contributing areas	Moderate	Not used	-
Drainage factors	Eroding sections of mains rivers	High	Used	Moderate
	Closeness to eroding streams	High	Used	Moderate
	Distance from stream initiation	Moderate	Not used	-
Geological factors	Lithological map	High	Used	Poor quality, location and content
	Soil type map	High	Not available	-
	Fault map	Moderate	Available but not used	Poor quality, needs revision
Land cover factors	Land cover existing	High	Not available	-
	Land cover (10 years old)	High	Used	Very poor quality information
	Land cover changes	High	Not available	-
	Road cuts	Very High	Used	Moderate
	Cuts for building construction	High	Not available	-
Triggering factors	Spatial distribution of rainfall	Moderate for spatial distribution	Not available	-
	Peak ground acceleration	Moderate	Not available	-
Landslides	Old landslides	Very high	Not available, partially made	Low quality
	Historic landslides	Very high	Used	Limited to roads

Table 2.1: Overview of input maps for landslide susceptibility assessment, with indication of their importance, and whether the data were available for the 3 test sheets used. Also the quality of the data for the 3 test sheets is indicated.

2.1 Map size and cartographic projection

For the generation of the factor maps used in the landslide susceptibility assessment it is very important to define the map boundaries, the size of the map sheets, the pixelsize of the raster maps used and the map projection.
All maps generated in the project should share the same map projection, and therefore also all the input maps should have this same projection. The map projection used for Vietnam has the following characteristics:

Projection	Tranverse Mercator
Ellipsoid	User defined
a	6378137.000
1/f	298.25722400
Datum	Molodensky
dX (m)	-191.904
dY (m)	-39.303
dZ (m)	-111.450
False Easting	500000.00000
False Northing	0.000000
Central Meridian	105^0 0’ 0’’ E
Central Parallel	0^0 0’ 0’’ N
Scale Factor	0.9999000000

Table 2.2: Projection parameters used for the map projection for the landslide maps in Vietnam.

The 1:50.000 scale landslide inventory maps are made for the topographic map sheets for the country.

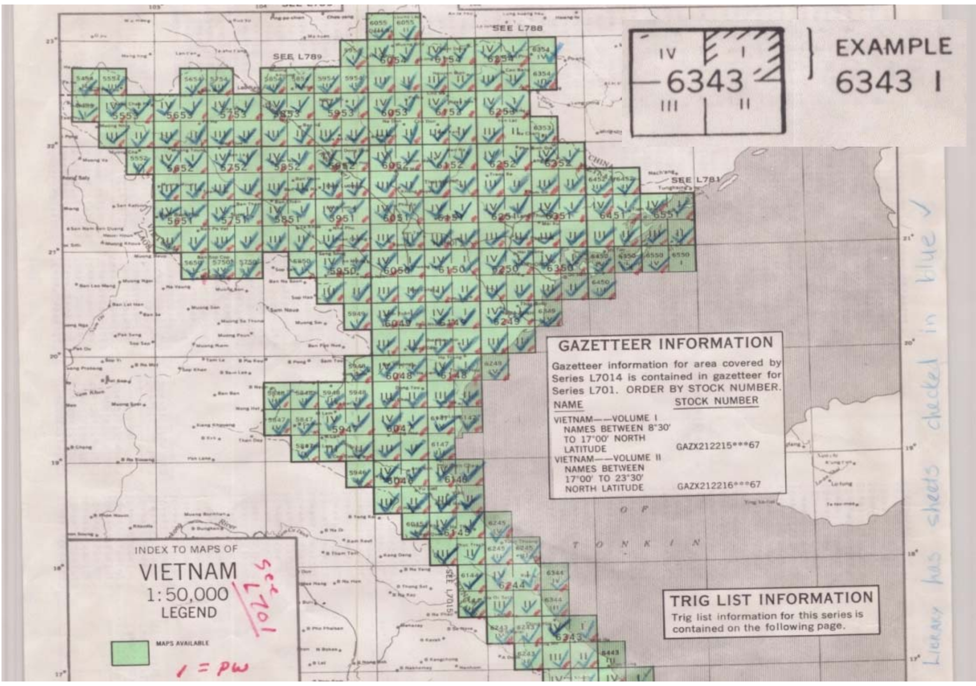


Figure 2.1: Index map of the 1:50.000 maps sheets of Vietnam. Only the northern part is shown here

The total number of maps sheets that have to be covered in the project is quite large. Therefore first a good estimation should be made of the priority areas for the map sheets to be produced.

In this pilot project we have carried out the work on three map sheets:

map	Province	Toposheet	Mapped by
1	Nghe Anh	E4817D	Mr. Hien
2	Nghe Anh	E4817A	Mr. Luu Binh
3	Thanh Hoa	??	Mr. Trinh Thanh

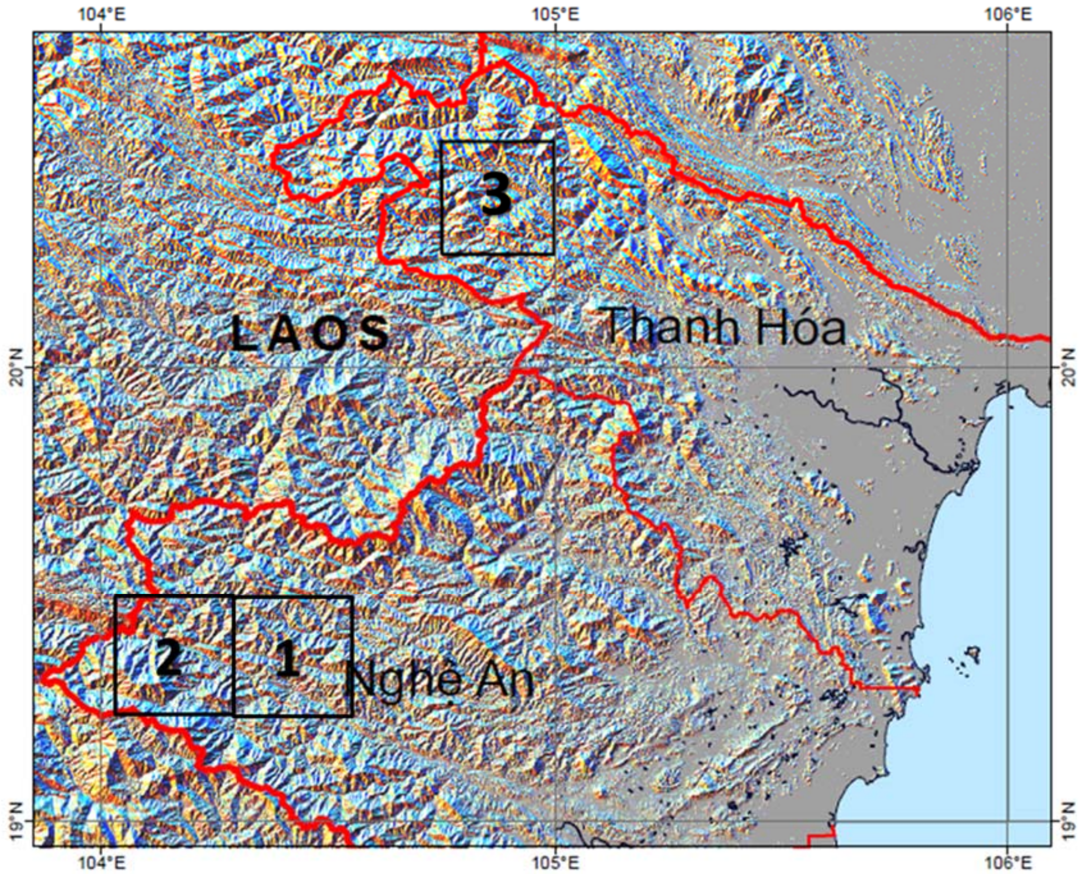


Figure 2.2 : Location of the three map sheets produced as test cases

Each map sheet covers an area of 723.524 km2, and has a dimension of 26.120km (X-Direction) and 27.700 km (Y-Direction). With a mapping scale of 1:50.000 this represents a map size of 52.24 cm (X-Direction) and 55.4 cm (Y-direction).

The pixelsize of the raster data is 10 meter, and therefore the raster maps have a dimension of 2778 lines and 2638 columns.

A smaller pixelsize is of course possible but this would make the run-out modelling with the Flow-R software extremely slow (in the order of several days). Therefore, given the scale and the level of detail a pixelsize of 10 meters is sufficient.

2.2 Topographic data

Topographic data at 1:50.000 scale is available for Vietnam in the form of contour lines with a contour interval of 10 meters from the Vietnam Natural Resources and Environment Cooperation. The quality of these maps is generally very good. From the same organization also other topographic information is obtained which matches very well with the contour lines, such as: drainage lines, roads, and buildings.

The contour lines are used for the generation of the digital elevation Model, through contour interpolation in a GIS such as ILWIS or ArcGIS. For an optimal representation of the Digital Terrain Models it is also important to incorporate Spot heights as points which mark the top of hills and ridges, as otherwise these would be represented as flat areas in the DTM. The DTM is generated as a raster map, ideally with a pixel size of 10 by 10 meters for

The contour lines are also used in the production of the final susceptibility maps. For this purpose the contour lines should be separated in main contour lines of 100 meter interval, for which also labels should be generated in the final map, as well as the 10 meter contour lines, which are displayed separately with a very thin line (0.1 mm)

The Digital Elevation Model is used for generating so-called hillshading maps, which are showing the terrain under a certain illumination. These maps are very important for several purposes:

1. For display purposes. Many of the thematic maps are normally displayed in transparency on top of the hillshading image, thus allowing the reader to get a better impression of the terrain;
2. For stereoscopic mapping. The Digital elevation Model together with the hillshading image can be used in the ILWIS software to generate a stereoscopic image of the hillshading, which is very useful for mapping geological structures, such as faults and lineaments, and also for detecting large landslides;
3. For final map production. As will be shown later, the hillshading map is a very important layer for the production of the final paper maps.

The Digital Elevation model is used for the generation of a number of so-called derivative maps. The most important one of these is the slope map. A slope map is generated using directional filters (in X and Y direction) which are combined with a Pythagoras rule (See for instance the explanation in the ILWIS help). The equation used for that is: SLOPEPCT = 100 * HYP(DX,DY)/ PIXSIZE(DEM) and SLOPEDEG = RADDEG(ATAN(SLOPEPCT/100)).

Slope gradient maps are essential in the generation of landslide susceptibility maps. It is possible to use the original slope angle values (in degrees) when using an SMCE-based approach for landslide susceptibility assessment (See later), in which the slope angle values are standardized between 0 and 1. It is also possible to create slope classes, in which the user first has to analyse which class boundaries are most relevant based on the relations between slope angles and landslide initiation points.

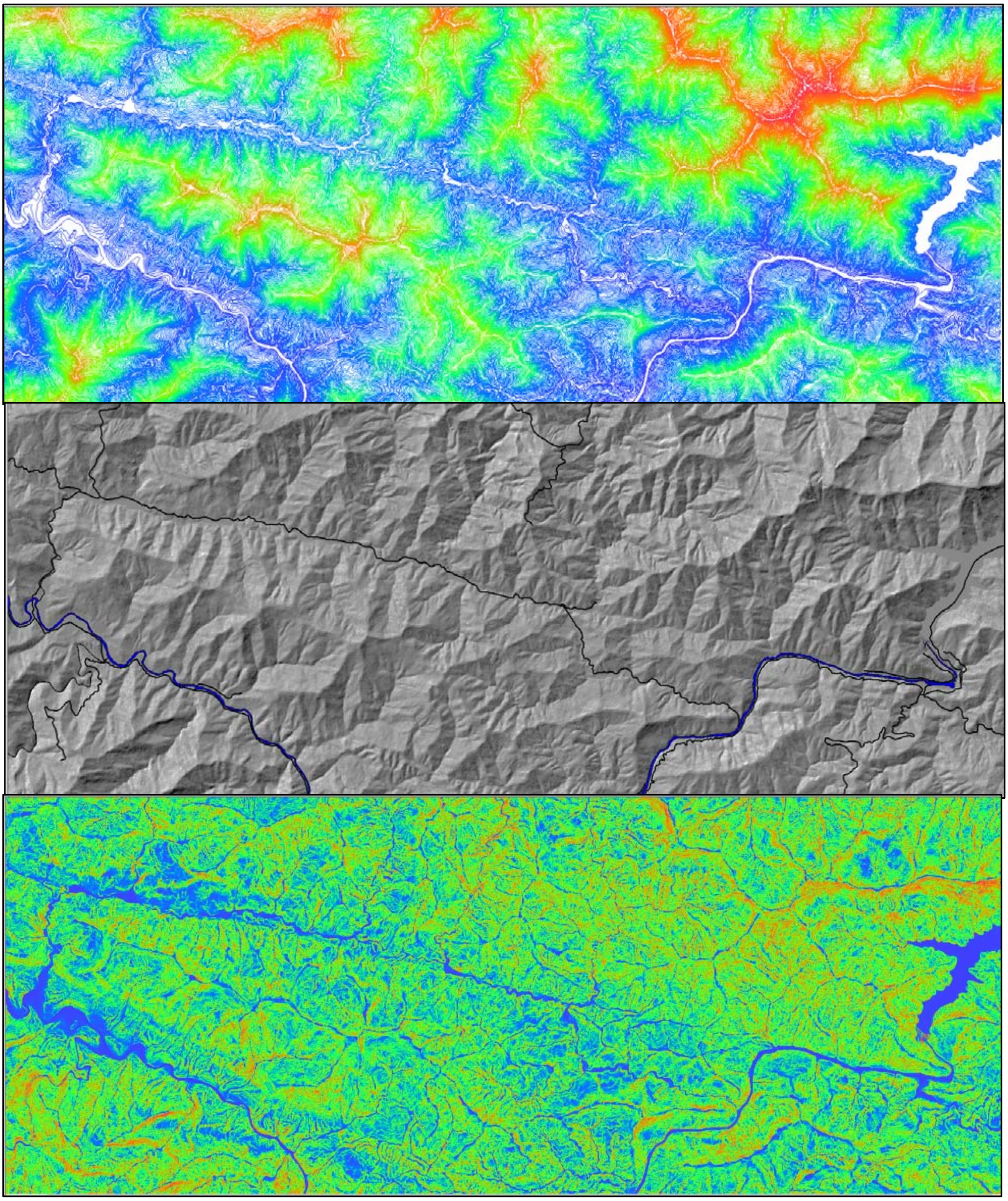


Figure 2.3: Example of topographic data from one of the map sheets. Above: contour lines with 10 meter contour interval, middle: hillshading image used for display purposes and final map production, Below: Slope map in degrees

Other derivatives from Digital Elevations Models that are often used in landslide susceptibility assessment are: slope direction, slope length, slope curvature, upslope contributing area, wetness Index etc. These indicators can be generated using GIS software like ArcMap or ILWIS using special programs related to hydro-tools. However, the user should be cautious in using too many topographic factors in the analysis as they are very much correlated, and they might amplify the importance of slope in relation to the other factors.

Also the causal relationship between the topographic factors and landslide occurrence might not always be very clear. For instance slope direction as such doesn't have a direct relationship with landslide occurrence. It is mostly through other indirect relationships. For instance, structural geology might have a relation with slope aspect (but also with slope angle), and also vegetation types might be different for different sun exposures. However, if these relationships are found it is much better to generate specific factors maps that represent these relationships than to simply use slope aspect classes.

In the three test maps sheets we only used the slope gradient as this is by far the most important topographic factor.

2.3 Drainage factors

Drainage obviously may have clear relationships with landslide occurrence. For instance the main rivers in the area may undercut the side slopes, leading to instability in these locations. Or vertically incising drainage channels may also cause failures in the valley slopes next to the stream. Another possibility is that the starting points of first order streams, due to the water accumulation in these locations might lead to landslides.

In order to take into account the effects of drainage as causal factors on slope stability it is important to keep the following things in mind:

Drainage lines should be separated in group, based on visual interpretation , and only the sections of the drainage lines that have active undercutting of the side slopes should be used as factor maps. When taking the entire river segments, large errors may occur as rivers may also flow through flat floodplains, where there is not instability effect of the drainage. So users should separate the drainage lines into eroding segments and non-eroding segments, and use only the eroding segments in the analysis.

Normally a certain distance from the drainage lines is used in which the effect of the erosion may cause landslide. Therefore users should decide what the maxmim distance is in which drainage lines still have an influence, and they should make a buffer that limits the factor to this distance. In the test maps sheets we have used a maximum distance of 200 meters for the main drainage lines, and 100 for the smaller ones.

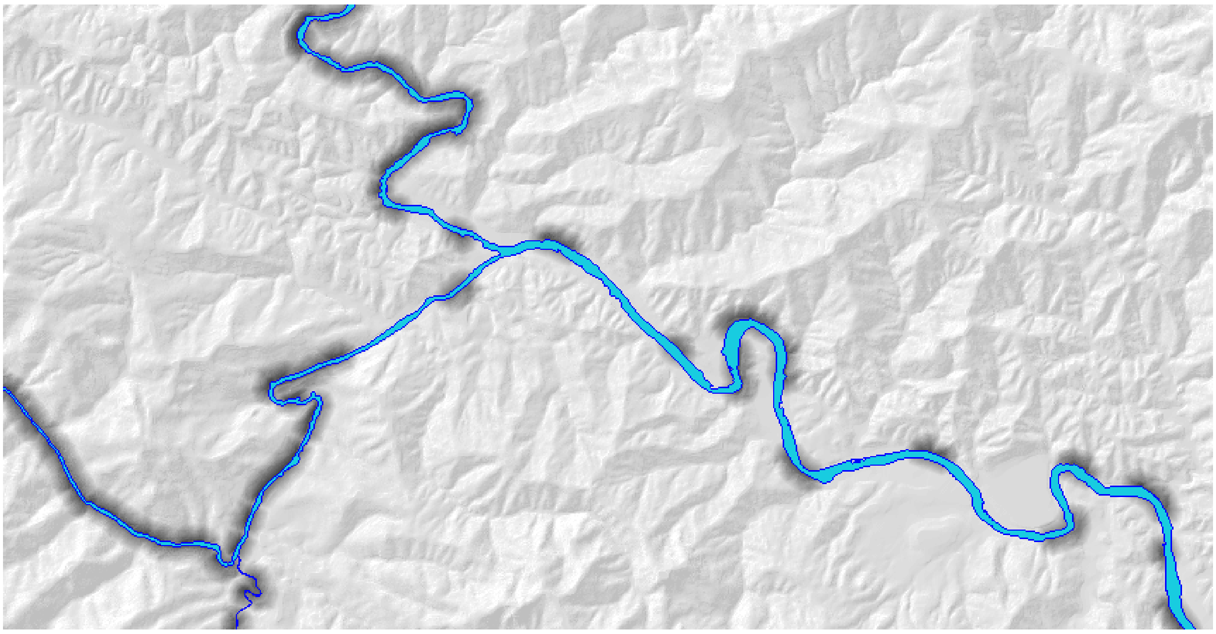


Figure 2.4: Example of the effect of using only the distance up to 200 meters from river segments that are eroding the side channels. Only the dark patches in the map are used as factor map in the landslide susceptibility assessment.

2.4 Geological factors

Together with slope steepness one of the major contributing factors to slope stability is the surface material, and its characteristics. Ideally the best factor map for landslide susceptibility assessment is based on a mapping of surficial materials, which can be either weathering soils, coluvial deposits, ancient landslide deposits, alluvial deposits, or anthropogenic deposits. Unfortunately such maps are not available at a scale of 1:50000 in Vietnam. Using such maps at much smaller scales (e.g. 1:100.000 or less) is not very useful as the relationship between the soil materials and the topography is essential and very generalized maps will only show strange combinations with topography. Therefore ideally a Geomorphological mapping uis first carried out based on visual stereo image interpretation by expert interpreters. They can map the landforms they see , and classify them as alluvial (e.g. flood plains, river terraces), denudational (e.g. old landslide complexes, alluvial fans, erosional areas), denudational-structural (e.g. evidences of fault scarps, relationship between structural geology and topography to identify areas with dipslopes, faceslopes, stronger rocks etc.) , and anthropogenic (e.g. mines, quarries, waste dumps, road cuts, dams etc.).

It is normally based upon such a detailed image interpretation that thematic maps are made for surface materials, but also for lithology and for faults and lineaments.

Lithology

As we do not have currently such maps available nor the presence of experience image interpreters we used the existing geological maps for the three test sheets. These maps are made at smaller scales than 1:50000 and these maps presented a number of problems:

- The information from different geological map sheets did not match, both in terms of the thematic information (different formation names along the boundaries of two adjacent maps) as well as with respect to the spatial units. Boundaries of lithological units did not match between two adjacent map sheets. This is illustrated in Figure 2.5

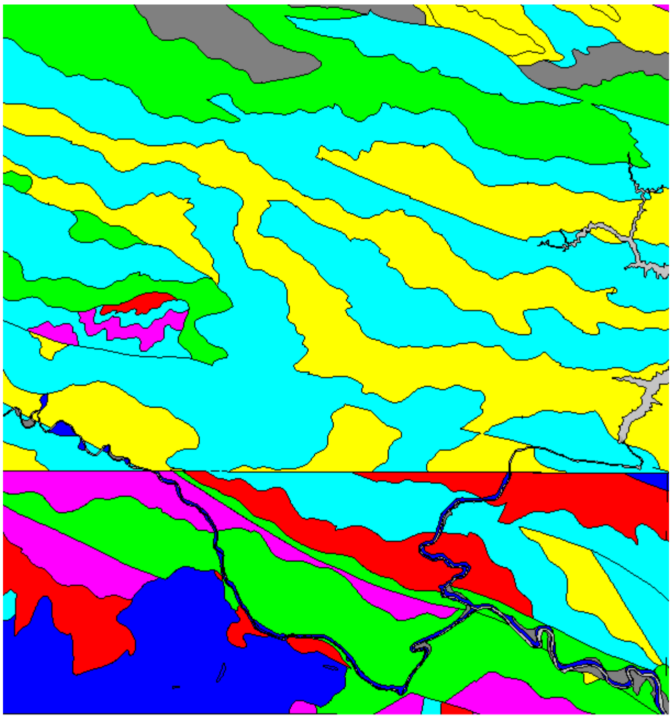


Figure 2.5: Illustration of the problems encountered with the exisiting lithological maps. Within the same map sheets two adjacent geological maps do not fit. Formation names change and boundaries do not match.

- The lithological units do not show a relationship with the topography. Whereas from the topographic expression an expert interpreter would certainly draw different boundary lines between the various lithological units, and also would make subdivisions within formations based on their rock strength as evidenced by differences in topography, these are not represented in the existing geological maps. This is illustrated in the Figure below

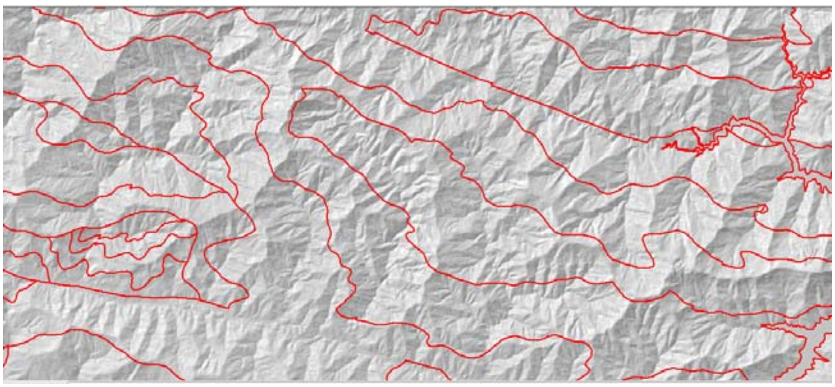


Figure 2.6: unclear relationship between topographic expression and lihtollgical units in the geological map.

The geological map units are based on formations, which contains a wide range of different lithologies that may have a very different relation with landslide occurrence. Therefore the geological units should be subdivided into smaller units based on topographic expression through image interpretation and further field work.

The work on the test map sheets revealed that it was very difficult for the landslide experts to indicate the relative importance of the various lithological units to slope stability. So in the expert-based weighting that was used it was very difficult to determine the weight of the individual lithological units. This could not be based on statistical relationships between existing landslides and lithology as nearly all landslides were along the roads, and no landslides were mapped outside of the road areas.

Therefore it is recommended to make more detailed geological maps as part of the landslide susceptibility assessment. This is quite some extra work, but the work should focus on:

- **Visual stereo image interpretation by expert interpreters using both stereo hillshading images, as well as stereo photos or satellite images, in order to better map the boundaries of lithological units.**
- **More geological evidence from the mapping teams that work in the field.**
- **Better understanding of the importance of the various lithological units in relation to landslide occurrence.**

Faults

Another important factor map that could be used in the landslide susceptibility assessment is a map of faults and lineaments. In the test study we decided not to use the existing fault maps as they were too general.

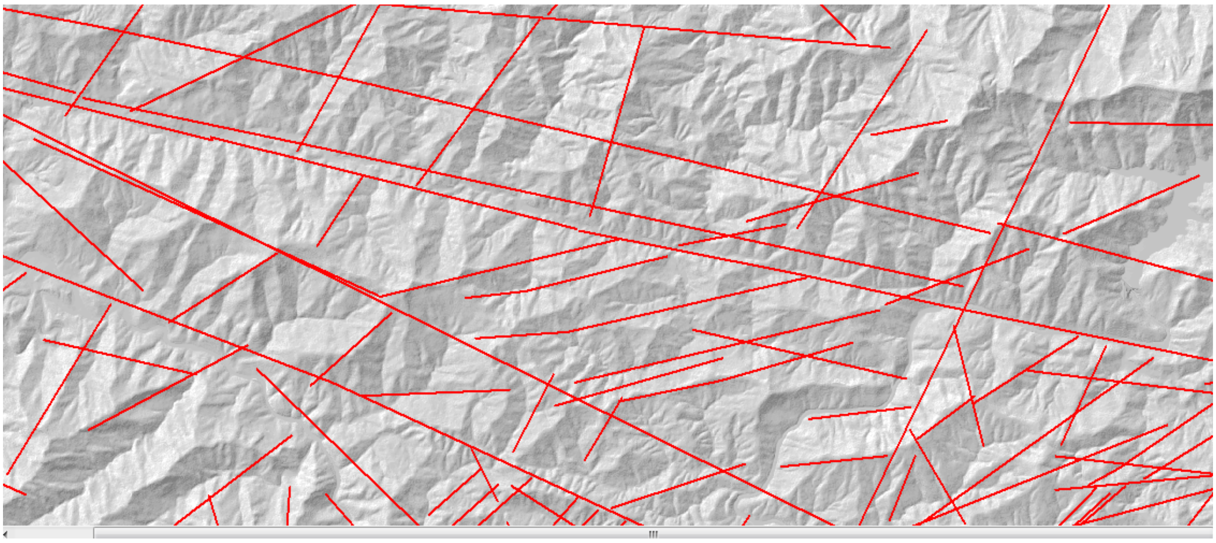


Figure 2.7: Example of an existing fault map, showing the problem that the faults and lineaments are undifferentiated, and are also very general, and lacking topographic expressions.

The existing fault maps didn't differentiate between faults and lineaments. Ideally a fault maps should indicate the main faults separately, and indicate whether the fault has neotectonic activity or not, and also indicate the fault type. The effect of the lineaments with landslide occurrence doesn't seem to be present, although that was difficult to judge based on the limited set of historica landslides that are mostly occurring along the roads. If a road runs along a valley that also is fault controlled it appears that there is a relationship with the fault, but this might be misleading.

The mapped faults in the existing maps also lack a clear relationship with topographic expression.

Users should be careful with the use of the factor "distance to faults" in the landslide susceptibility assessment. It is not wise to use large distance buffers as there is no apparent relation with landslides and faults that are a few kilometres away. The exception is of course for active faults, and there the relationship between the distance to the ruptured fault does exist, but it is not so simple as also the fault mechanism (normal fault, reverse fault, trust fault, lateral fault) and the part of the terrain in relation to the fault (hanging wall, footwall) as well as the expected rupture length, depth of the earthquake and earthquake magnitude plays a role. As most of Vietnam doesn't have earthquakes over Magnitude 6 (which is generally considered the minimum magnitude to generate coseismic landslides at an important scale), it is therefore not advised to use large buffers around faults in the landslide susceptibility assessment.

The other relationship between faults and landslides is that in the actual faultzone the rocks are more fractured and therefore the weathering depth might be larger and the material properties less than in other areas. In such cases it is advisable to use a buffer that is equivalent in width to the actual fault zone, but will be in general less than 100 meters.

Therefore also for the generation of usable fault maps for the landslide susceptibility assessment we advise to :

- **Carry out visual stereo image interpretation by expert interpreters using both stereo hillshading images, as well as stereo photos or satellite images, in order to better map the faults in relation to lithological differences and topographic expressions.**
- **More geological evidence from the mapping teams that work in the field on fault locations and characteristics of the width of the fault zone.**

2.5 Land cover factors

One of the most important factors for the occurrence of landslides is the change in land cover, either due to anthropogenic activities (e.g. clearing of forest for agricultural land, construction of roads with inadequate design of road cuts, construction of cutslopes for housing construction) or due to natural activities (e.g. forest fires). In order to be able to assess the relationship between these landcover changes and land slide occurrences, it is important to:

- Map the land cover for different periods in time, and generate a map of land cover changes, rather than static land cover maps.
- Map the landslides for specific periods of time which can be linked to the land cover changes that have occurred over that period of time.

The test study in the three map sheets revealed that the current land use maps are of a very low quality. This is illustrated in Figure 2.8

Initially there were several land cover maps available for the study obtained from different organizations. However, most of these land cover maps werwe generated at small scales, and were far too general to be used in this study. When they were compared with the available imagery (both airphotos from early 2000 and high resolution satellite image downloaded fr4om Google Earth) there was no relation whatsoever between the images and the land cover maps. We therefore diced not to use these. The maps that were used were derived from the topographic map. However, as can be seen from Figure they too showed a very bad correlation with the available images.

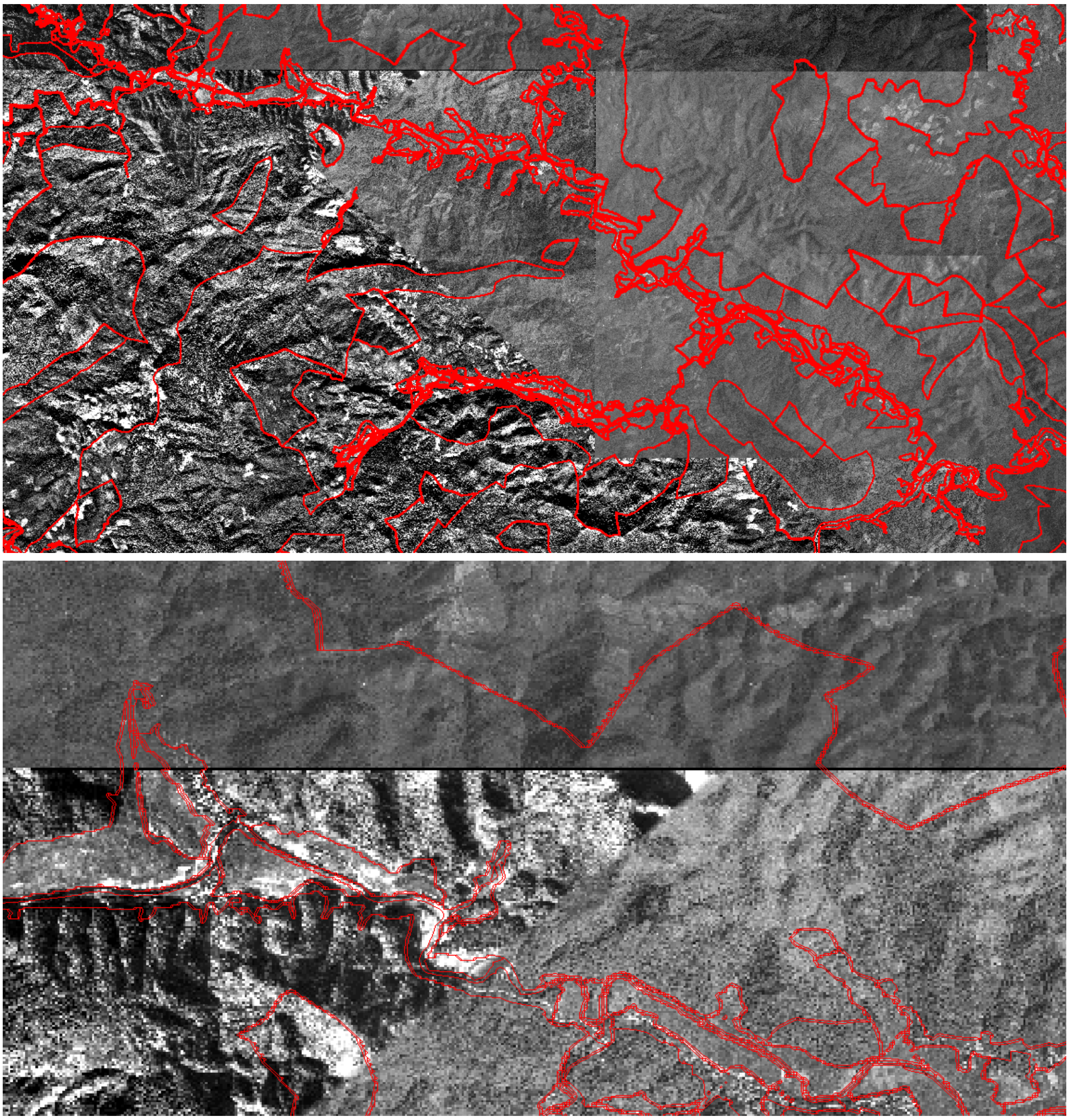


Figure 2.8: Example of the problems involved in the existing land cover maps. The above image shows the boundaries of the land cover units on top of the available aerial photographs. There doesn't seem

to be any relationship, except for the areas close to the river. The lower figure also shows the problems iof using the existing aerial photographs, as they are very different in quality.

We can therefore conclude that the available land cover maps are next to useless for this study and that new land cover maps should be generated in order to be able to use them as factor maps in the landslide susceptibility assessment.

One of the major developments in the three test sites is the use of so-called shifting cultivation. Local farmers cut the forest and use the land for agriculture during a short period, before they abandon the land and cut another agricultural field in another place. This makes that the land use patterns differ very much between two subsequent dates of images (e.g. over a period of 10 years time). As this type of land use practices is known to cause landslide problems in other parts of the world, it is very relevant to take this into account in the landslide susceptibility assessment.

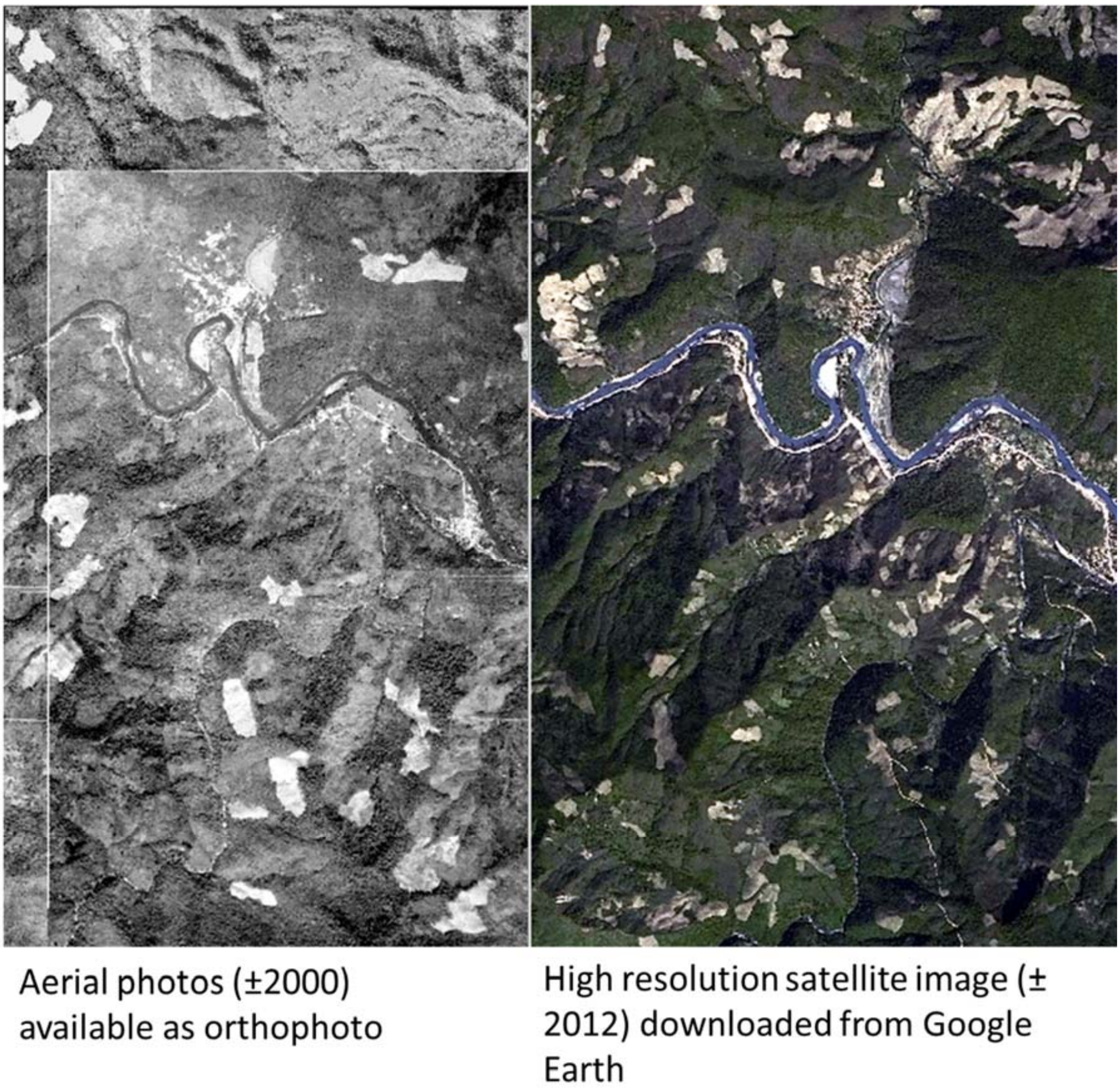


Figure 2.9: Examples of the large land cover changes over time due to shifting cultivation. Left: Aerial photograph from about 200, right: high resolution satellite image downloaded from Google Earth from 2012.

Therefore we propose that two land cover maps are produced through stereo visual image interpretation by expert interpreters:

- **A land cover map based on the available airphotos from the early 2000. This should be done in combination with the mapping of other features: lithology, faults and landslides.**
- **A land cover map based on the recent high resolution images from Google Earth, or**
- **A land cover map generated through image classification of high resolution satellite images (e.g. ASTER images, SPOT images). This requires expertise in image processing. Based on these land cover maps from two periods a land cover change map is then produced which is used as a factor map in the landslide susceptibility assessment.**

Roads

By far the most important factor for landslide occurrence in the three test areas, at least when you base yourself on the existing landslide distribution map, are the roads. Nearly all mapped landslides occur close to roads, and especially close to road cuts along the roads. As this is such an important factor, we therefore decided to split this factor into a number of classes (See Table ?).

	With road cut		Without a road cut	
	Above eroding river	Without River Erosion	Above eroding river	Without River Erosion
Main road				
Secondary road				

The road segments were split up into one of these 8 categories, based on the comparison with the hillshading image and through image interpretation. An example of such a classification is given in Figure 2.10. By subdividing the road into these classes it is possible to assign more weight to those sections of the road that have both a road cut upslope and an eroding river downslope. The subdivision of road segments can be further improved, e.g. by incorporating the passage of the road over old landslide deposits, or the presence of road stabilization measures and their conditions (e.g. cracks in retaining walls etc.).

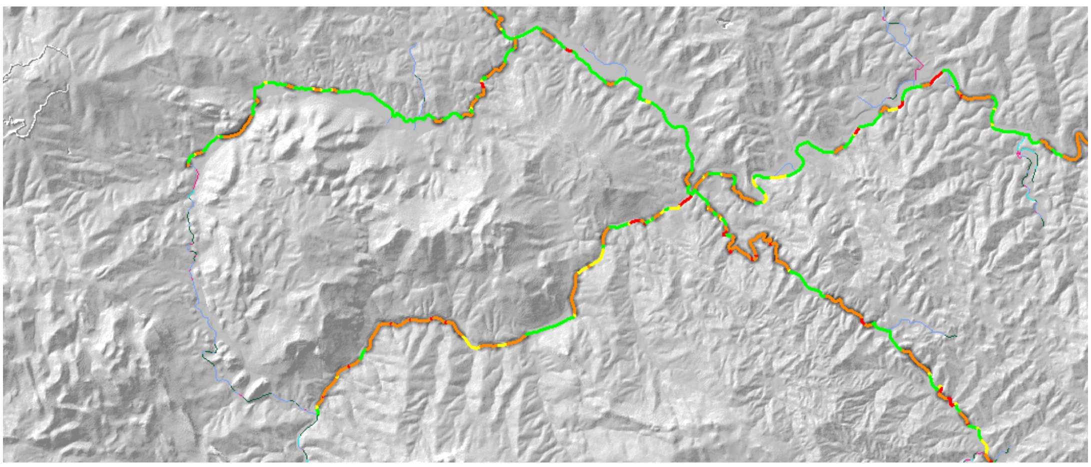


Figure 2.10 : Example of the classification of roads into different segments based on the presence of road cuts above the road, and the presence of eroding river on the downslope part of the road.

The distance from the road segment that is used as a factor in the landslide susceptibility assessment is another important aspect. The distance in which a road is of influence is considered limited to about 100 -150 meters upslope of the road. Therefore only small buffer distances were used in the analysis.

One of the major problems in the use of the susceptibility maps in relation to road construction is that the landslide susceptibility map which is prepared before a road is constructed, doesn't indicate that much with respect to the expected landslides once a road is constructed. The construction of the road alters the initial conditions completely and therefore the susceptibility map prior to road construction cannot predict the landslide occurring after the road construction. This is also illustrated in Figure 2.11

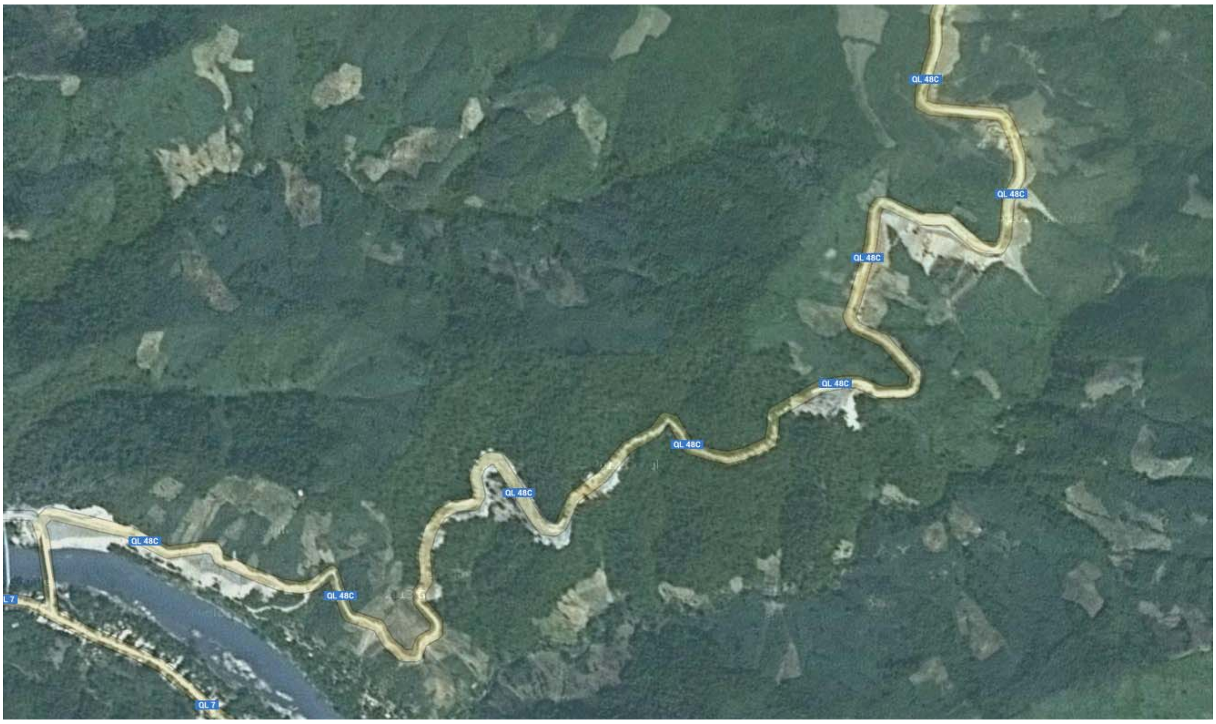


Figure 2.11: Example of impact of recent road construction on slope stability. Due to many cutslopes and dumping of materials new landslides develop rapidly after road construction.

This implies that the factor maps have to be updated regularly and that also the landslide susceptibility maps need to be updated regularly. This requires a fixed procedure for the production of the maps and a well-managed repository of all input maps used for the generation of the landslide susceptibility for one map sheet.

Cutslopes above buildings

In some parts of Vietnam (e.g. Yen Bai) the construction of cutslopes to make room for the construction of buildings in sloping terrain is one of the most important contributing factors for landslide occurrence. Therefore these cutslopes should be carefully mapped, and classified according to their height and age. This building cutslope map is then also used as a factor map in the susceptibility assessment.

3. Generation of the Landslide inventory maps

Landslide inventories are the basis for assessing landslide susceptibility, hazard and risk. They are essential for susceptibility models that predict landslide on the basis of past conditions: we need to know where they happened and how many. These conditions are used to predict future ones: we need to know the causal factors. These conditions differ for different landslide types: we need to know what happened. Temporal information is essential to estimate the frequency of landslides: we need to know when they happened. Landslide inventories are used to validate landslide susceptibility, hazard and risk maps.

Landslides generally isolated, rather small but frequent occurring events. This means they are visible for some time but quickly become difficult to recognize. Fresh landslide scarps become overgrown by vegetation within a few years after they happen. Signs of landslides become difficult to interpret from images. On the other hand major triggering events such as tropical storms might cause many landslides at the same time, and then it is important to rapidly map the landslides triggered by that event so that we can link the temporal probability of the triggering rainfall to the spatial probability of landslide occurrence.

Therefore the generation of landslide inventories and a landslide database is a tedious procedure. Often there is no single agency that has the responsibility for maintaining a landslide database. In the project VIGMR has been assigned the task of doing this. Information on landslides comes from a variety of sources. Reporting has to come from field mapping, asking local people in the field, available archives, newspapers, image interpretation, and image processing.

Table 3.1 gives an overview of the methods that are considered useful for the generation of landslide inventory maps in other guidelines. They can be classified into the following main groups:

- Image interpretation
- (Semi) automatic classification
    - Based on spectral information
    - Based on altitude information
- Field investigation
- Archive studies
- Dating methods
- Monitoring networks

In the project the limiting factors are the availability of the data and the scale of analysis (1:50000) Suitable data for the semi automatic detection of landslides from InSAR, LIDAR or Photogrammetry are not considered at this moment feasible options for the landslide inventory mapping in Vietnam. The automatic classification of landslides using Object Oriented Image Classification is an option that might be explored especially for mapping event-based inventories linked to major triggering events like tropical storms/cyclones or earthquakes. However, this requires a considerable resource financially for the acquisition of high resolution satellite images. Therefore the main methods useful for Vietnam are image interpretation from airphotos and satellite imagery, use of historical archives, interviews with local people and field mapping.

Group	Technique	Description	Scale			
			Regional	Medium	Large	Detailed
Image interpretation	Stereo aerial photographs	Analog format or digital image interpretation with single or multi-temporal data set	M	H	H	H
	High Resolution satellite images	With monoscopic or stereoscopic images, and single or multi-temporal data set	M	H	H	H
	LiDAR shaded relief maps	Single or multi-temporal data set from bare earth model	L	M	H	H
	Radar images	Single data set	L	M	M	M
(Semi) automated classification based on spectral characteristics	Aerial photographs	Image ratioing, thresholding	M	H	H	H
	Medium resolution multi spectral images	Single data images, with pixel based image classification or image segmentation	H	H	H	M
		Multiple date images, with pixel based image classification or image segmentation	H	H	H	M
	Using combinations of optical and radar data	Either use image fusion techniques or mult-sensor image classification, either pixel based or object based	M	M	M	M
(Semi) automated classification based on altitude characteristics	InSAR	Radar Interferometry for information over larger areas	M	M	M	M
		Permanent scatterers for pointwise displacement data	H	H	H	H
	LiDAR	Overlaying of LiDAR DEMs from different periods	L	L	M	H
	Photogrammetry	Overlaying of DEMs from airphotos or high resolution satellite images for different periods	L	M	H	H
Field investigation methods	Field mapping	Conventional method	M	H	H	H
		Using Mobile GIS and GPS for attribute data collection	L	H	H	H
	Interviews	Using questionnaires, workshops etc.	L	M	H	H
Archive studies	Newspaper archives	Historic study of newspaper, books and other archives	H	H	H	H
	Road maintenance organizations	Relate maintenance information along linear features with possible cause by landslides	L	M	H	H
	Fire brigade/police	Extracting landslide occurrence from logbooks on accidents	L	M	H	H
Dating methods for landslides	Direct dating method	Dendrochronology, radiocarbon dating etc.	L	L	L	M
	Indirect dating methods	Pollen analysis, lichenometry and other indirect methods,	L	L	L	L
Monitoring networks	Extensometer etc.	Continuous information on movement velocity using extensometers, surface tiltmeters, inclinometers, piezometers	-	-	L	H
	EDM	Network of Electronic Distance Measurements, repeated regularly	-	-	L	H
	GPS	Network of Differential GPS measurements, repeated regularly	-	-	L	H
	Total stations	Network of Theodolite measurements, repeated regularly	-	-	L	H
	Ground-based InSAR	Using ground-based radar with slide rail, repeated regularly	-	-	L	H
	Terrestrial LiDAR	Using terrestrial laser scanning, repeated regularly	-	-	L	H

Table 3.1: Overview of methods that can be used for landslide inventory mapping at different scales. The right columns indicate the suitability (H=high, M=Moderate and L=Low) for the particular method at a particular scale of analysis. The red boxes indicate the methods that are considered appropriate for mapping landslides within this project in Vietnam.

At this moment the use of image interpretation is considered the most important input source. But it is also difficult because suitable imagery is often not available. It must be high-resolution satellite images or airphotos, otherwise a lot of landslides are missed. Also currently there is a lack of expertise in image interpretation in VIGMR.

3.1 Image interpretation

Image interpretation can be defined as **the study of the imaged objects of the earth surface, the extraction of those features relevant to the object of study, the analysis of the selected features with the objective to come to a deduction of their significance for the specific field of study**.

Stereoscopic aerial photographs are important tools to recognize and map landslides. The interpretation of aerial photography is an empirical and subjective process. It is a systematic scanning of a stereo model assisted by logical and scientific evidences. Aerial photo interpretation (API) is an art as much of a science, and it requires well trained, experienced investigators.

Photo-interpretation is based on: the experience of the photo-interpreter, the available images for interpretation, the size of the area that need to be covered and the procedures and criteria of interpretation. Within the project a two weeks training course was given for about 50 staff members on image interpretation and field checking in April 2013. The participants were asked to

- Make an interpretation of landslides from the anaglyph of an Aerial photo in Black and White from 2000 and screen digitize the landslides on the orthoimage.
- Make an interpretation of landslides from the anaglyph of a downloaded high resolution satellite image from 2012 from Google Earth image and screen digitize the landslides on the ortho image.
- Make an interpretation of landcover from the anaglyph of the Aerial photo and screen digitize the landcover on the orthoimage.
- Make an interpretation of landcover from the anaglyph of the Google Earth image and screen digitize the landcover on the orthoimage.
- Make an interpretation of faults and lithology from the anaglyph of the Google Earth image & aerial photo and digitize the them on the orthoimage.

For the interpretation the following simple procedure was proposed: mapping the landslides as polygons, separating between scarp and body, assigning a unique identifier to each landslide and describe each landslide with a number of attributes. This is illustrated in Figure 3.1 and Figure 3.2.

Interpreted image

Checklist for landslide interpretation

Type	Subtype	Activity	Depth	Body
Fall Topple Slide Spread Flow	Rotational Translational Complex Unknown	Stable Dormant Active	Surficial Deep	Scarp Body

Attribute table linked to interpreted image

Slide	Part	Type	Subtype	Activity	Depth	Body
001	01	Slide	Rotational	Active	Deep	Body
001	02	Slide	Rotational	Active	Deep	Scarp

Figure 3.1: Simplified procedure for landslide interpretation

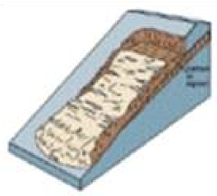
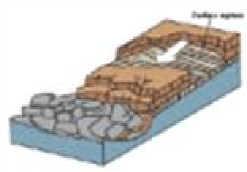
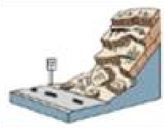
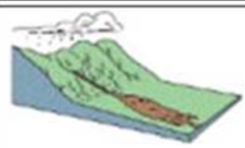
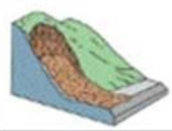
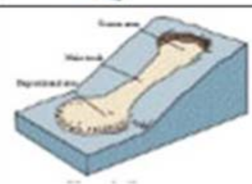
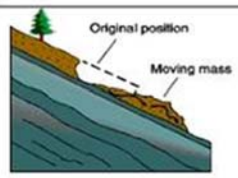
Type	Characteristics	Example
Rotational Slide	**Morphology:** Abrupt changes in slope morphology, characterized by concave (niche) - convex (run-out lobe) forms. Often step-like slopes. Semi-lunar crown and lobate frontal part. Backtilting slope facets, scarps, hummocky morphology on depositional part. D/L ratio 0.3 - 0.1 , **Vegetation:** Clear vegetational contrast with surroundings, the absence of landuse indicative for activity. Differential vegetation according to drainage conditions. **Drainage:** Contrast with not failed slopes. Bad surface drainage or ponding in niches or backtilting areas. Seepage in frontal part of run-out lobe.	
Translational slide	**Morphology:** Joint controlled crown in rockslides, smooth planar slip surface. Relatively shallow, certainly in surface mat. over bedrock. D/L ratio <0.1 and large width. Run-out hummocky rather chaotic relief, with block size decreasing with larger distance. **Vegetation:** Source area and transportational path denudated, often with lineations in transportational direction. Differential vegetation on body, in rockslides no landuse on body. **Drainage:** Absence of ponding below the crown, disordered or absence of surface drainage on the body. Streams are deflected or blocked by frontal lobe.	
Rock Block slide	**Morphology:** Joint controlled crown in rockslides, smooth planar slip surface. Relatively shallow, certainly in surface mat. over bedrock. D/L ratio <0.1 and large width. Run-out hummocky rather chaotic relief, with block size decreasing with larger distance. **Vegetation:** Source area and transportational path denudated, often with lineations in transportational direction. Differential vegetation on body, in rockslides no landuse on body. **Drainage:** Absence of ponding below the crown, disordered or absence of surface drainage on the body. Streams are deflected or blocked by frontal lobe	
Rockfall	**Morphology:** Distinct rockwall or free face in association with scree slopes (20 -30 degrees) and dejection cones. Jointed rock wall (>50 degrees) with fall chutes. **Vegetation:** Linear scars in vegetation along frequent rock fall paths. Vegetation density low on active scree slopes. **Drainage:** No specific characteristics.	
Debrisflow	**Morphology:** Extensive coverage of materials with high content of mud and boulders in a fan shaped form, either deposited on alluvial fans at the outlet of valleys, or on the foot of a slope. **Vegetation:** absence of vegetation everywhere; sometimes large trees still stand and are engulfed in flow, or tree stumps still there. **Drainage:** disturbed on body; original streams blocked or deflected by flow.	
Debris avalanche	**Morphology:** relatively small, shallow niches on steep slope (>35 degrees) with clear linear path; body frequently absent as it eroded away by stream **Vegetation:** Niche and path are denuded or covered by secondary vegetation. **Drainage:** Shallow linear gully can originate on path of debris aval.	
Earthflow	**Morphology:** One large or several smaller concavities, with hummocky relief in the source area. Main scars and several small scars resembles slide type of failure. Path following streamchannel and body is infilling valley, contrasting with V shaped valleys. Lobate convex frontal part. Irregular micromorphology with pattern related to flow- structures. D/L ratio very small **Vegetation:** Vegetational on scar and body strongly contrasting with surroundings, landuse absent if active. Linear pattern in direction of flow. **Drainage:** Ponding frequent in concave upper part of flow. Parallel drainage channels on both sides of the body in the valley. Deflected or blocked drainage by frontal lobe.	
Flowslide	**Morphology:** Large bowlshaped source area with step-like or hummocky internal relief. Relative great width. Body displays clear flowstructures with lobate convex frontal part (as earthflow). Frequent associated with cliffs (weak rock) or terrace edges. **Vegetation:** Vegetational pattern are enhancing morphology of scarps and blocks in source area. Highly disturbed and differential vegetation on body. **Drainage:** As on earthflows, ponding or deranged drainage at the rear part and deflected or blocked drainage by frontal lobe.	

Figure 3.2: Example of the characteristics of different mass movement types that be recognized through stereo image interpretation.

The results from the 2 week training course showed that most of the participants had no experience in landslide interpretation. Later on during the 6 weeks workshop with the 3 VIGMR staff preparing the 3 test maps, they also spend about 1.5 week on photo interpretation. However also their results were still not good enough to be used in the final map. Therefore extensive image interpretation training is needed in this stage of the project.

3.2 Landslide mapping

For the landslide inventory that will be carried out for the 1:50000 scale landslide susceptibility mapping throughout Vietnam, a clear structure of the work has to be adopted. In this section an explanation is given of the proposed procedure. A landslide inventory map consists of points and polygons:

- **Polygons**. Only the landslides that are larger than 50 * 50 m will be represented as polygons. This means that on the map this is 1*1 mm. Polygons are made for:
  - Scarp area /erosional part
  - Accumulation area / body

  The polygons also have points in the centre. The points receive a unique landslide ID.

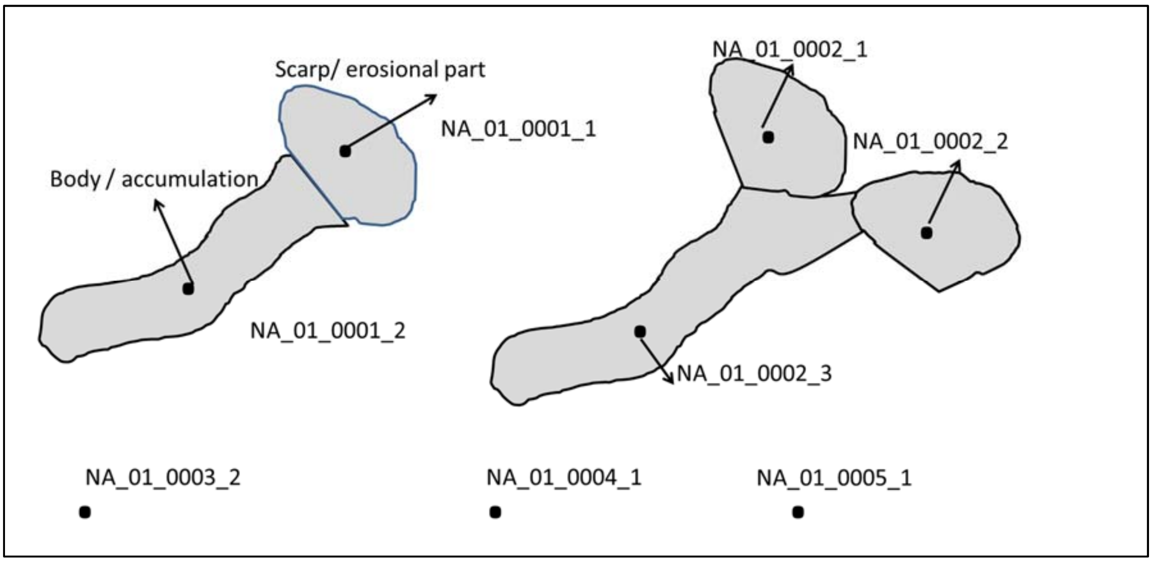


Figure 3.3: The proposed organization of the landslide mapping in either polygons or points.

- **Points.** The points related to the polygons and the points of the landslides that are smaller than 50*50 m are the ones that relate to attribute data.

The points should have the following attributes that contain information on the province, map sheet, and unique landslide ID. Also it should be indicated whether the point refers to a polygon or not.

ID	Landslide_ID	Polygon	Province	Map sheet	Part	X	Y
NA_01_001_1	NA_01_001	1	NA	01	S		
NA_01_001_2	NA_01_001	1	NA	01	B		
NA_01_002_1	NA_01_002	1	NA	01	S		
NA_01_002_2	NA_01_002	1	NA	01	S		
NA_01_002_3	NA_01_002	1	NA	01	B		
NA_01_003_1	NA_01_003	0	NA	01	U		
NA_01_004_1	NA_01_004	0	NA	01	U		
NA_01_005_1	NA_01_005	0	NA	01	U		

Table 3.2 : Example of a table linked to the mapped landslide points.

Apart from these the following attributes are collected during the image interpretation part:

ID	Type	Activity_Photo	Activity_Google	Landuse_Photo	Landuse_Goolge	Cause
NA_01_001_1						
NA_01_001_2						
NA_01_002_1						
NA_01_002_2						
NA_01_002_3						
NA_01_003_1						
NA_01_004_1						
NA_01_005_1						
Etc.						

Explanation on the attributes:

Part: Which part of the landslide?

Code	Meaning
S	Scarp area
B	Accumulation area
U	Undifferentiated (if unknown or in the case of landslides that are only located as points)

Type: landslide type

Code	Type	Speed of movement	Subtype
FAFA	Rockfall	Fast	-
SDFT	Deep seated landslide	Fast	Translational
SDFR			Rotational
SDFC			Complex

SDST		Slow	Translational
SDSR			Rotational
SDSC			Complex
SSFT	Shallow landslide	Fast	Translational
SSFR			Rotational
SSFC			Complex
FLSM	Flow	Slow	Mudflow
FLFD		Fast	Debrisflow

Activity (both in photo as in the Google Earth Image)

Code	**Name**	**Meaning**
A	Active	Clear signs of recent activity
D	Dormant	No clear signs of recent activity but landforms are clear so that the landslide happened some time ago.
S	Stable	No clear signs of recent activity and no clear landforms
N	Not visible	No landslide visible.

Landuse (both in photo as in the Google Earth image)

Use the same landuse classes as the ones in the available landuse maps

Code	**Vietnamese Name**	**Meaning**
	t.b.d.	
		Bare soils
		Agriculture field
		Settlement
		Grassland/Shrubs
		Forest
		Water

Cause : Possible causes.

You may best use simple ASCII text to indicate the observable causes from the image interpretation. Or you can also make a list with codes.

Code	**Vietnamese Name**	**Meaning**
	T.b.d.	
		Road cut with inappropriate drainage
		Building cut with too steep slope
		Road is running on an old landslide
		Etc….

It is extremely important to generate also the photo-interpretation maps for each map sheet. In the following figures some example are given

.

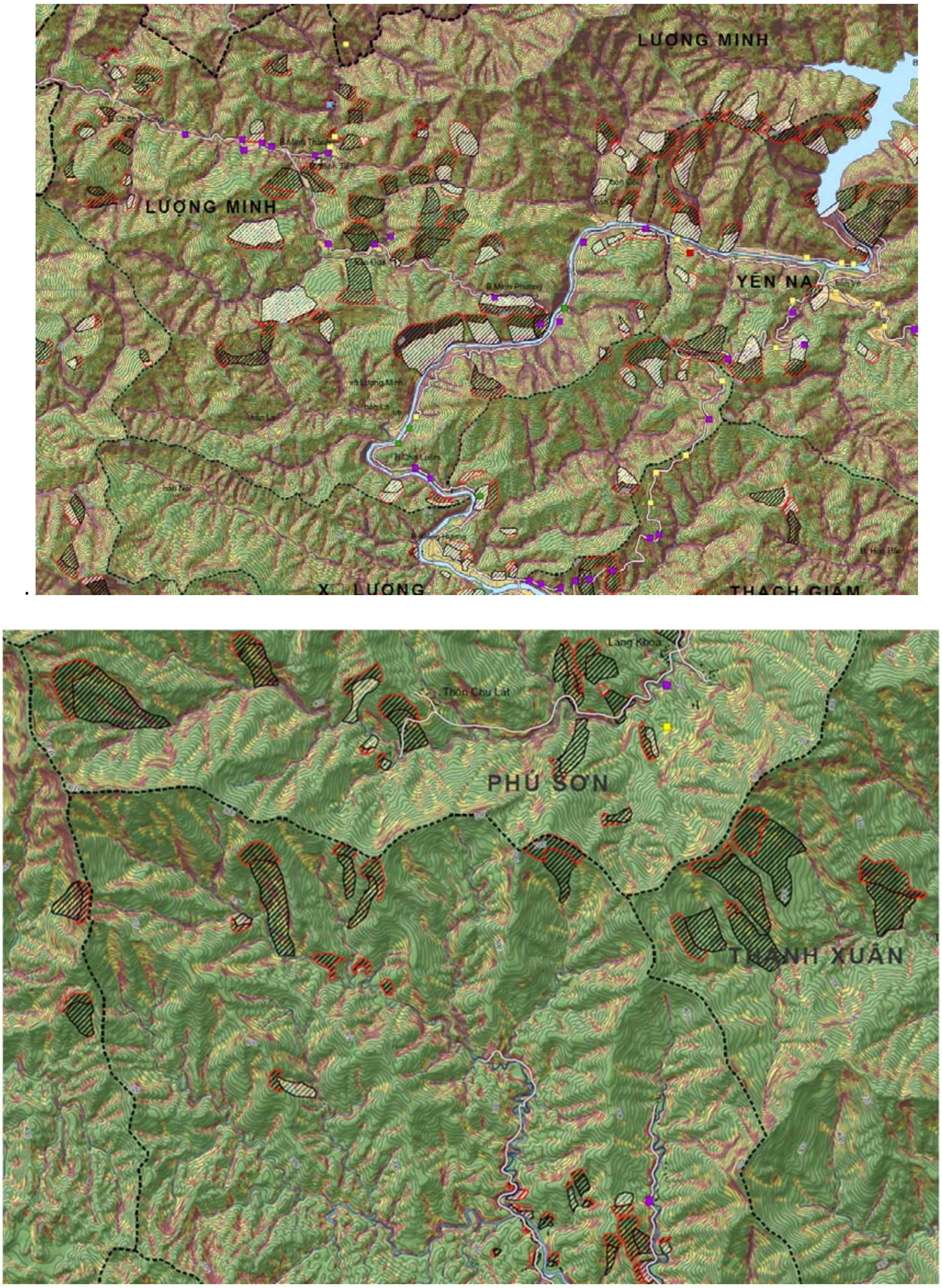


Figure 3.3: Examples of the overlay of photo-interpreted landslides on the landslide susceptibility map.

3.3 Landslide inventory from historical archives

It is essential to compile landslide information from historical archives in order to get more information on the date of occurrence and the areas affected. The following types of information should be consulted:

- News media archives
- Community archives
- scientific, geological and technical documentation;
- technical-administrative documentation produced or gathered by mostly public bodies;
- national and local periodicals, regularly published from the mid 1800s on;
- historical, archaeological and naturalistic literature, both published and unpublished;
- Historical maps
- Old photographs

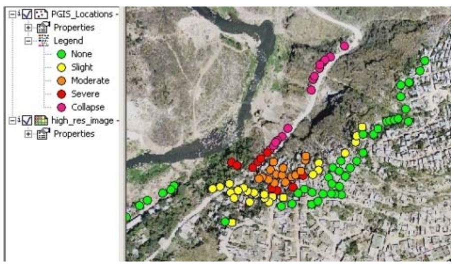
Through this type of study it is possible to obtain:

- the date of activation (with varying degrees of precision, depending on the event);
- the administrative location (Province, Municipality);
- the area affected by the movement
- the main descriptive characteristics of the landslide;
- the triggering mechanisms (if indicated in the original documents);
- the dimensional parameters (if indicated in the original documents);
- the effects on the territory and on anthropic action, plus any interference with the hydrographic network, when available;
- information sources;

This work needs to be done by specialists in historical analysis together with a landslide expert in order to:

- Define if it was a landslide
- Locate it on a map
- Translate the information into useful data for the database
-

3.4 Collection of landslide information from local people



One of the best sources for landslide information are the local residents, as they are the ones that have been affected by them and they might have the best information on their location and date of occurrence. Community-based disaster risk assessment and management projects have been very successful in many parts of the world, and should also be investigated in this project in Vietnam. From other experiences, e.g. in Thailand, it is possible to gain a lot of insight into the way such projects are set-up. Also as part of the field mapping geologist can be trained to make use of the knowledge of the local population. Questionnaires, interviews and workshops with local community leaders will give you a lot of information on landslide occurrences. Local people know the best what has happened when and where. However, It may take time to do this. The local residents should be taken seriously and the geologist must be interested in them. The information should be cross checked as local residents might give the wrong information for certain reasons.

3.5 Field mapping

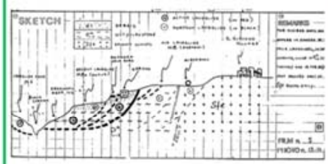
In the field the landslides have to be checked and described in more detail. There more detailed information can be collected on the landslides, which is explained in the tables below.

- Mapped by (person)
- Date of mapping
- Certainty
  - (inferred, confirmed)
- Landslide component
  - (scarp, transport, accumulation)
- Landslide type
  - (combination of type and subtype, Cruden and Varnes method)
- Landslide activity
  - State of activity
  - Style of activity
- Landslide age
  - Exact date
  - Reactivation date
  - Inferred date
  - Source of date information

- Landslide depth
  - How determined
  - Range (min, max)
- Landslide volume
  - How determined
  - Range (min, max)
  - Initiation/accumulation
- Landslide speed
  - Speed class
  - How determined
- Causal factors
  - Contributing factors
  - Triggering factors
- Lithology
  - Rock type
  - Weathering class & depth
  - Structural geology
- Landuse
- Damage
- Stabilization measures
- Elements at risk
- Causal factors:

- Landuse
  - Above initiation area
  - In scarp area
  - In accumulation area
  - Any recent landuse changes
- Damage
  - Transportation lines
  - Buildings
  - People affected
- Stabilization measures
  - Which methods
  - Are these intact / functioning?
  - Which methods could be implemented?
- Elements at risk
  - What is currently at risk?
  - Transportation lines
  - Buildings
  - People affected

- Level of threat:
  - Importance of this landslide
  - Requirement for detailed study
- Sketch (profile):



- Sketch map:

ID = Landslide ID

Type			**Relative age**		**Runout length**	Estimated
1	Soil slide		1	< 2 year ago	**Runout angle**	Estimated
2	Debris slide		2	Last decade	**Landslide volume**	Estimated
3	Rockslide		3	Last 50 years	**Possible causes**	Mention specific ones only
4	Earth flow		4	Older than 50	**What is at risk?**	Mention nr / length
5	Debris flow		**Velocity**			
6	Flow slide		1	Within seconds		
7	Rock fall		2	Minutes/hour		
Depth			3	Days		
1	< 2 meter		4	Creep		
2	2-5 meter		**Component**			
3	5-10 meter		1	Scarp		
4	10-50 meter		2	Transport		
Activity			3	Accumulation		
1	Active		**Movement**			
2	Not but can reactivate		1	Rotational		
3	Not		2	Translational		
			3	Other		

4. Landslide susceptibility assessment

4.1 Available methods

There are many different methods for landslide susceptibility assessment. The selection of the optimal method depends on the size of the study area, the amount of available data, the scale of analysis and the experience of the susceptibility analysts. Figure 4.1 gives an overview of the available methods. For the landslide susceptibility project in Vietnam at scale 1:50.000 the use of physically-based modelling is not possible, as the parameterization of such models is not feasible for such large areas. Ideally a combination of statistical methods and expert-based methods should be used, in which the emphasis is on either one of the two, depending on the knowledge of the contributing factors, and the availability of sufficient landslide information.

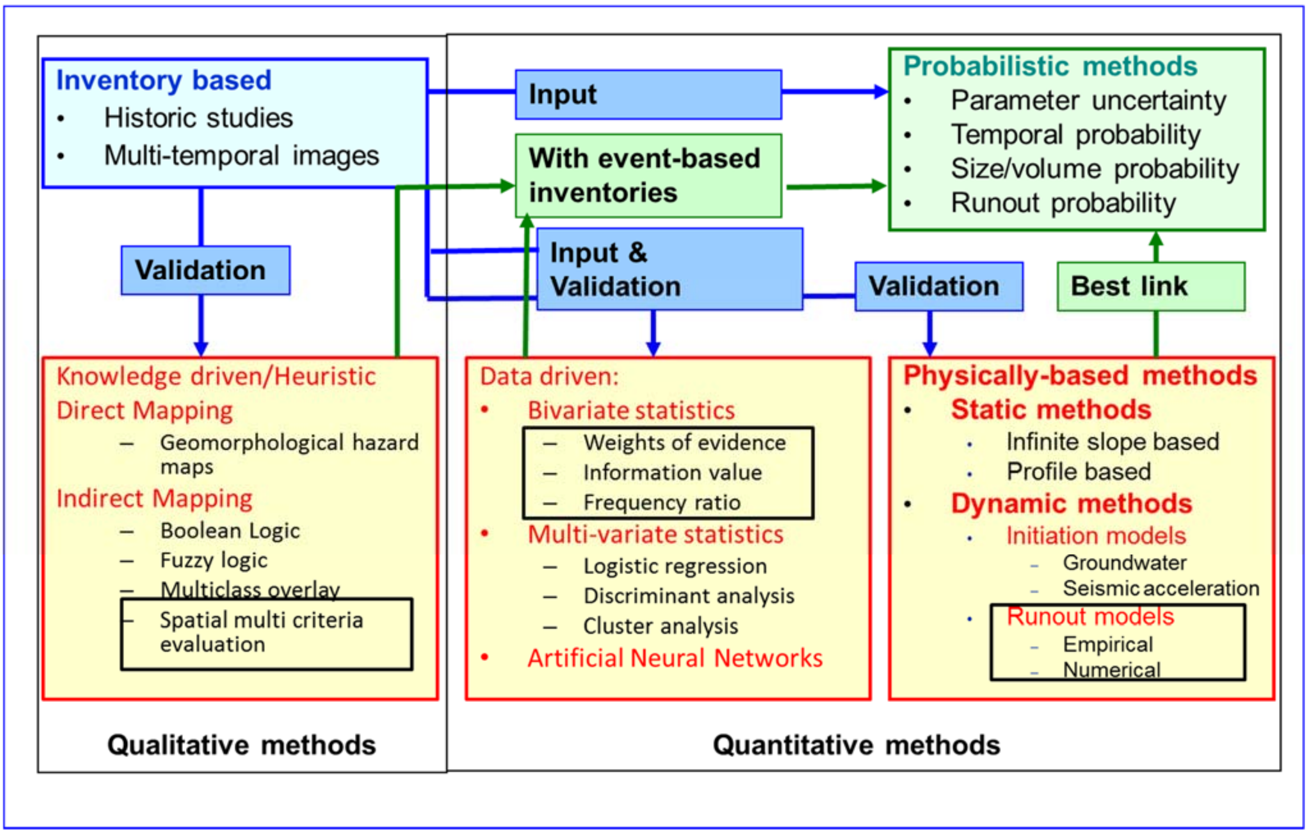


Figure 4.1: General classification of methods that can be used for landslide susceptibility assessment. In this case we suggest to use a combination between Knowledge driven and data driven methods for initiation susceptibility assessment.

When enough landslides are available in the landslide inventory, it is advisable to use bi-variate statistical methods as exploratory tool to learn which contributing factors, or combinations of contributing factors are important in the study area. There are several useful tools available that can be used with a conventional GIS system, without the need of external statistical models. Some of these tools are shown in Figure 4.2. These methods basically calculate landslide densities within the contributing factors, or the classes of the contributing factors, and then compare these with the overall density in the map. Also in ArcMap there are extensions for making these calculations, such as ARC-SDM (http://www.ige.unicamp.br/sdm/default_e.htm)

Frequency ratio method

$$FR = \frac{\text{Area of landslides in Class / Area of all Landslides}}{\text{Area of Class / Entire map}}$$

Hazard Index method

$$FR = LN\left[\frac{\text{Area of landslides in Class / Area of Class}}{\text{Area of all landslides in the map / Area of Entire map}}\right]$$

Weights of evidence method

$$W_i^+ = \log_e \frac{P\{B_i|S\}}{P\{B_i|\bar{S}\}}$$

$$W_i^- = \log_e \frac{P\{\bar{B}_i|S\}}{P\{\bar{B}_i|\bar{S}\}}$$

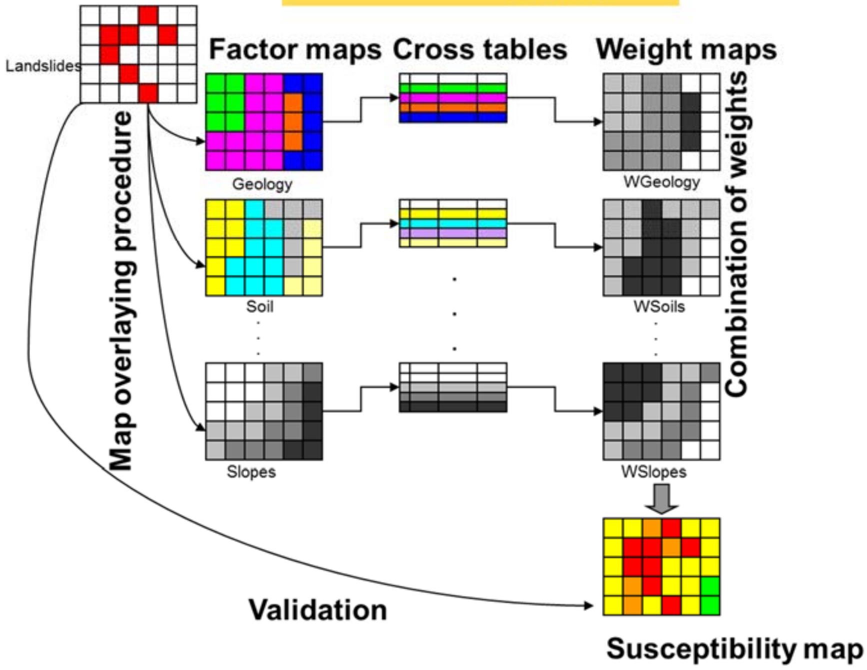


Figure 4.2: Above: three examples of bi-variate statistical methods that are easily applicable. Below a: simplified procedure for the application of bi-variate statistical methods in a GIS.

Landslide susceptibility assessment using statistical methods is considered an attractive methods by many researchers, as it is an objective method, which is also reproducible. This means that the same results could be obtained if it was repeated by other persons. However, this is not really true, as the method very heavily depends on the quality of the landslide inventory maps, and the contributing factor maps. And even more so it depends on the knowledge of the person that carry out the assessment. Such methods cannot be automated. They will also require a very substantial expert-based input, in deciding which factors (or combinations of factors) contribute to the occurrence of landslides.

Black box methodologies are very dangereous, and should be avoided. Expert-knowledge is essential, and high quality input data is essential. Also is landslide studies the saying is true: rubbish in-rubbish out

4.2 Important considerations

This section evaluates a number of important aspects that should be taken into account when selecting the susceptibility method.

We first evaluated the historical field-checked landslide points, and discovered that the large majority of them was located along the road. which are mostly along the roads. This is illustrated in the figure below. And for the landslides which appeared to be located away from the mapped road, it also became clear that the road maps were not completely up to date, and that also these points were mainly along the road.

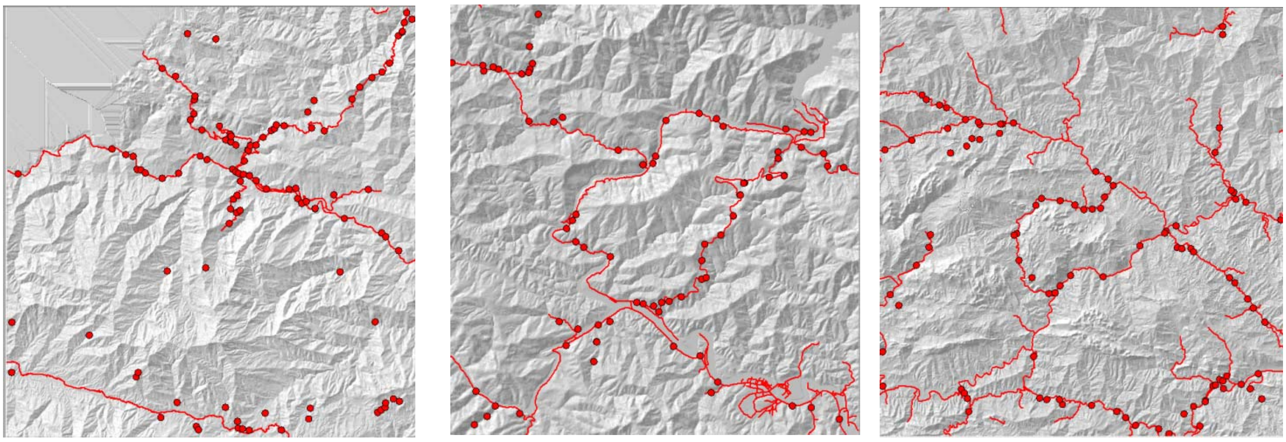


Figure 4.3: Very close relationship between the mapped landslides and the roads in the three test map sheets.

The question was whether landslides in this area:

1 are really occurring mainly along the roads, or
2 whether the field geologist had concentrated their mapping basically only along the road.

If 1 is true, this has important consequences for the landslide susceptibility mapping. If landslides occur predominantly along the roads, then making a road buffer in relation to cutslopes and some other factors might already be sufficient. However, how to classify the rest of the terrain in terms of landslide susceptibility? If a new road is constructed in an area where currently no landslides occurred, and thus where the susceptibility map indicates low susceptibility, it is very likely that new landslides will be generated. Therefore the questions is then: what is the exact aim of a landslide susceptibility in such a case?

If 2 is true, it means that many more landslideshave happened in the areas away from the roads. In that case extensive landslide inventory mapping has to be made through image interpretation. The problem is then however: how old are these landslides, and do the conditions that caused these landslides still prevail today? Is the land cover under which the landslides happened the same as now? Many landslides seem to have been caused by shifting cultivation. In order to map them good quality imagery is then needed for different time periods. This is illustrated in the Figure below. The figure shows an example of very high resolution images for an area south of Nghe Anh, where it is possible to identify landslides related to roads, but also many landslides away from the roads, and also signs of burning of forest for shifting cultivation.

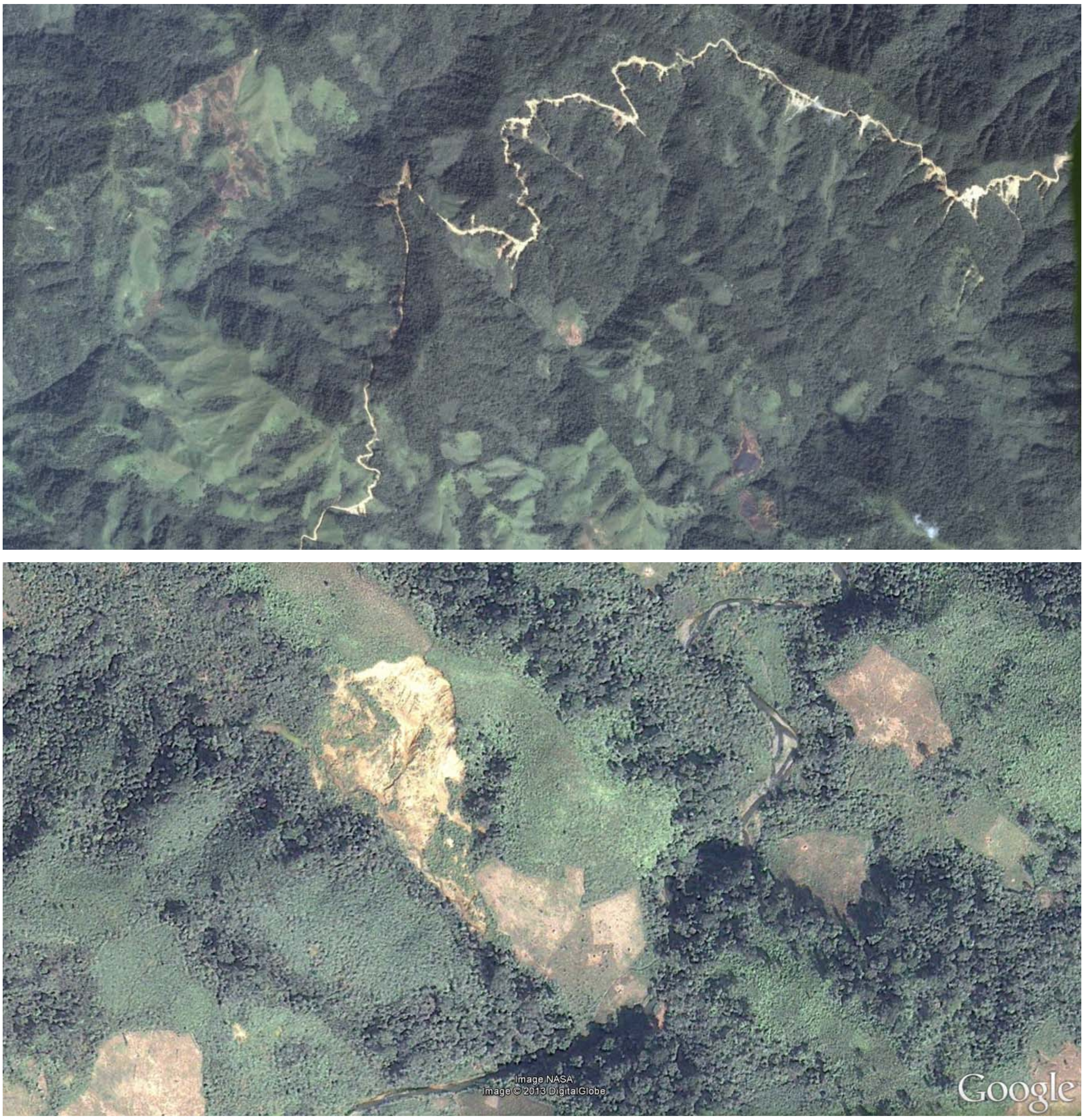


Figure 4.4: Example of a very high resolution image for an area south of Nghe Anh in Google Earth which allows the mapping of landslides away from the road, and the detection of burned areas used in shifting cultivation.

The three VIGMR staff also tried to digitize landslides from the airphotos, but given the short time, and the limited experience, they only did it for a limited part (about a quarter) of the map sheet. The mapped landslides are still not very reliable. The landslides were checked also by an expert image interpreter (Michiel Damen). He concluded that most of the landslides that were interpreted by the three VIGMR staff were not correct. They were mostly covering too large areas. Therefore Michiel

Damen interpreted about 1 quarter of each map. He couldn't complete the whole area and also not map all the landslides in the quarter of the map due to lack of time.

We encountered some severe problems that did not justify the use of statistical methods for landslide initiation assessment:

- For a statistical approach we require a sufficiently large landslide dataset that is related to different failure mechanisms, and contains different landslide types. Table 4.1 gives an overview of the available information for the landslide points in the three map sheets. Although the overall number per sheet is reasonable, the large majority occurs along the roads, and are rotational failures. The date information is still rather incomplete and needs to be further improvement before it can be used in a temporal frequency analysis.

	Sheet 1	**Sheet 2**	**Sheet 3**
Number of landslide points	80	112	97
Type information	Complex 41 Flow 1 Rockfall 1 Rotational 26 Topple 9 Translational 2	Complex : 31 Mudflow: 7 Rockfall: 3 Rotational: 69 Translational: 2	Complex : Mudflow: Rockfall: Rotational: Translational:
Volume information	Not available	Yes, for all, ranging from 450 to 13000	Not available
Date information	Old_landslides : 6 Rainfall_season_in_2009: 1 Rainfall_season_in_2010: 2 Rainfall_season_in_2011: 45 Rainfall_season_in_2011_2012 : 18 Rainfall_season_in_2012 : 7	Old Landslides: 16 2010-2011: 5 2011-2012: 25 2012 : 60 Other : 6	Not available
Road cuts / natural slope	Natural slopes: 18 Cut slope: 62	Natural slopes: 32 Cuts slope: 80	Not available

Table 4.1: Summary of landslide characteristics for the available landslide point maps for the 3 test maps.

- Since the majority of the existing landslides that have been mapped in the field are located along the roads, the use of a statistical method would have resulted in a very large susceptibility along roads and a low susceptibility elsewhere, as the factor "close to roads" would have dominated very much over the other factors.
- One major difficulty is when we would also include the scarps of the photo-interpretated landslides into account in the statistical analysis, we do not know the relative age of these and therefore would not use the current landuse to correlate with the landslide occurrence. Land cover change as a factor would probably be much better.

The best approach for landslide initiation susceptibility assessment at a scale of 1:50000 is the use of statistical methods in combination with expert-based weighting approaches. Since we do not have a very reliable landslide data set, we only used the landslides to check the statistical relation with the factor maps, but did the actual landslide initiation susceptibility map using Spatial Multi-Criteria evaluation.

For the three map sheets the following procedure was followed for the susceptibility assessment. We used the following data:

- Slope angles from the contourlines (good data)
- Distance from different types of roads (with or without roadcuts, and close to the rivers, and main and secondary roads). We adapted the existing road layers based on image interpretation to generate these classes, and we made distance buffers around them.
- Distance from eroding parts of the river. We used the river polygon lines for that and recoded the segments into eroding segments and non-eroding segments. Then we made distance buffers around them.
- The lithological unit. The available lithological maps are very bad. We encountered many problem, as they often do not fit with the other data, and there are big differences between mapsheets, which all have to be adjusted manually. We didn't have much time to do this for all of the sheets. Also the geological map is very general and doesn't seem to have good relation with what can be seen in the airphotos. So for other map sheets there needs to be a team that will focus on improving the geological maps.
- The land use and landcover maps were really problematic. They were either not fitting the rest of the data and were often extremely general and didn't show any relation with the airphotos. Also the landuse data from different times was not correct. They tried to fix the problem but making a landuse map for the entire sheet requires a lot of time. So in the end the landuse maps are not reliable. The best landuse map to start with are those derived from the topographic maps. But they need to be edited a lot. For the production of the landslide susceptibility maps, a team is needed that focuses entirely on the production of reliable landuse maps. I propose that two landuse maps are made: one based on the topographic maps which is updated based on the airphotos (ten years ago), and one which is based on the Google Earth image (recent). We will then also calculate the difference in landuse in the last ten years and use that as one of the factor maps
- We didn't use the faults and lineaments yet, because the maps are still rather unreliable and we didn't see any specific relation with the available landslides.

4.3 Landslide initiation assessment

Spatial multi criteria evaluation is a technique that assists stakeholders in decision making with respect to a particular goal (in this case a qualitative risk assessment). It is an ideal tool for transparent group decision making, using spatial criteria, which are combined and weighted with respect to the overall goal. For implementing the analysis in the case study, the SMCE module of ILWIS was used. The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardized and weighted in a criteria tree. The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).

The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardised and weighted in a 'criteria tree.' The output is one or more 'composite index map(s),' which indicates the realisation of the model implemented. See Figure 4.5

From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in the figure above. The matrix A contains the criteria in one axis (C1 to Cn), and a list of possible alternatives, from which a decision has to be taken on the other axis (A1 to Am). Each cell in the matrix (aij) indicates the performance of a particular alternative in terms of a particular criterion. The value of each cell in the matrix is composed of the multiplication of the standardised value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W1 to Wn) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a11 to a1n for alternative A1).

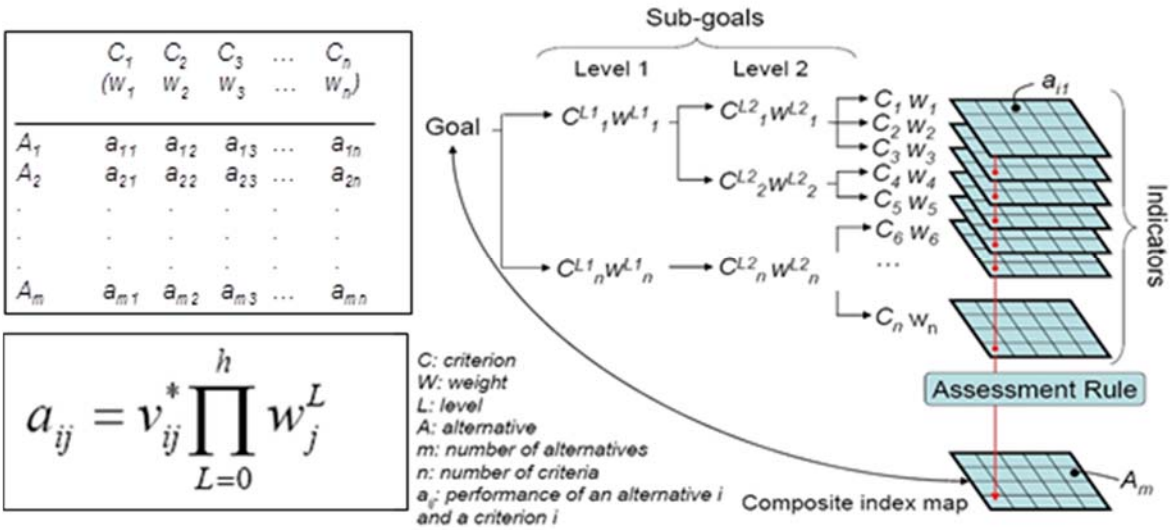


Figure 4.5: Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

For implementing this matrix according to the AHP, three principles steps need to be considered. The first one decomposes the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (Cj) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative Aj. The goal (risk index) has been decomposed into criteria levels CL1 and CL2. The intermediate levels are often indicated as sub-goals or objectives (e.g. in level 1, the sub-goals are a 'hazard index' and a 'vulnerability index'). Each criterion of each level will also have an assigned weight. Therefore, the values for the layers of the intermediate levels are obtained through the summation of the performance for the alternative at lower levels. As the criteria consist of raster maps, their spatial performance (aij) and the alternative (Ai) will be identified for particular raster cells.

The composite risk index map is obtained by an assessment rule (sometimes also called decision rule), which is calculated by adding up the performance of all cell values of the different criteria (aij) for the particular alternative. However, the performance of every element in the matrix (aij), is obtained in a different way (See equation in Figure 4.5).

In this equation, vij refers to the standardised value of criterion (Cj) for alternative (Ai), and weight wLj refers to the weight of criterion (Cj) for level L (0–h levels). During the analysis, it could be desirable (and sometimes necessary for a better definition of the weights wLj) to produce the intermediate criteria maps.

General steps in the process are:

- **Definition of the problem**. Structuring of the problem into a criteria tree, with several branches or groups, and a number of factors and/or constraints.
- **Standardization of the factors**. All factors may be in different format (nominal, ordinal, interval etc.) and should be normalized to a range of 0-1. SMCE has some very handy tools for that especially for value data, making use of different transformation graphs.
- **Weighting of the factors within one group**. SMCE has some very handy tools for that derived from Analytical Hierarchical Processing (AHP), such as pair wise comparison and rank ordering.
- **Weighting of the groups**, in order to come to an overall weight value.
- **Classification of the results**.

The resulting criteria tree structure for the map sheets is given in Figure 4.6, 4.7 and 4.8

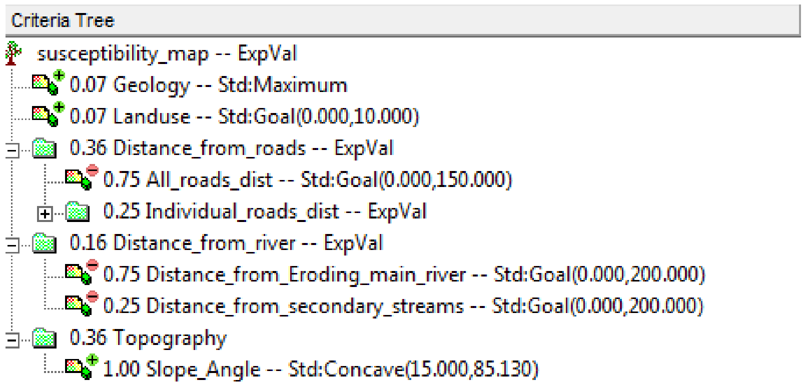


Figure 4.6 : Criteria tree used for landslide initiation assessment for the test data map nr 1.

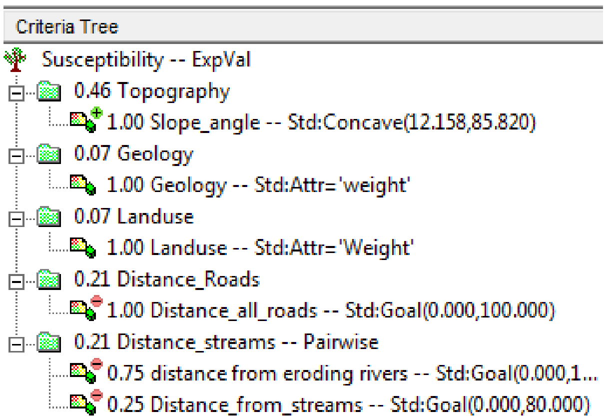


Figure 4.7 : Criteria tree used for landslide initiation assessment for the test data map nr 2.

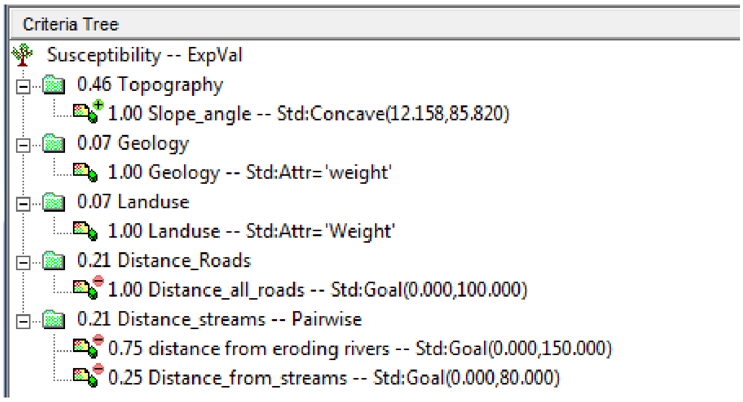


Figure 4.7 : Criteria tree used for landslide initiation assessment for the test data map nr 3.

It is very important to state here that this method doesn't propose to come to a fixed number of contributing factors or to fixed weights that should be used. In each map sheet the experts that do the mapping should decide what the main contributing factors are, what their relative importance is , and assign the weights.

We generated landslide initiation susceptibility maps, and classified them into 3 classes (high, moderate and low). Figure 4.8 shows the resulting susceptibility map for map nr 1, with some detailed areas. It is clear that in the results the slope steepness, together with the closeness to roads and eroding sections of rivers play the most important roles. Due to the poor quality of the geological map and land cover map these have also not been given too much emphasis in the weighting.

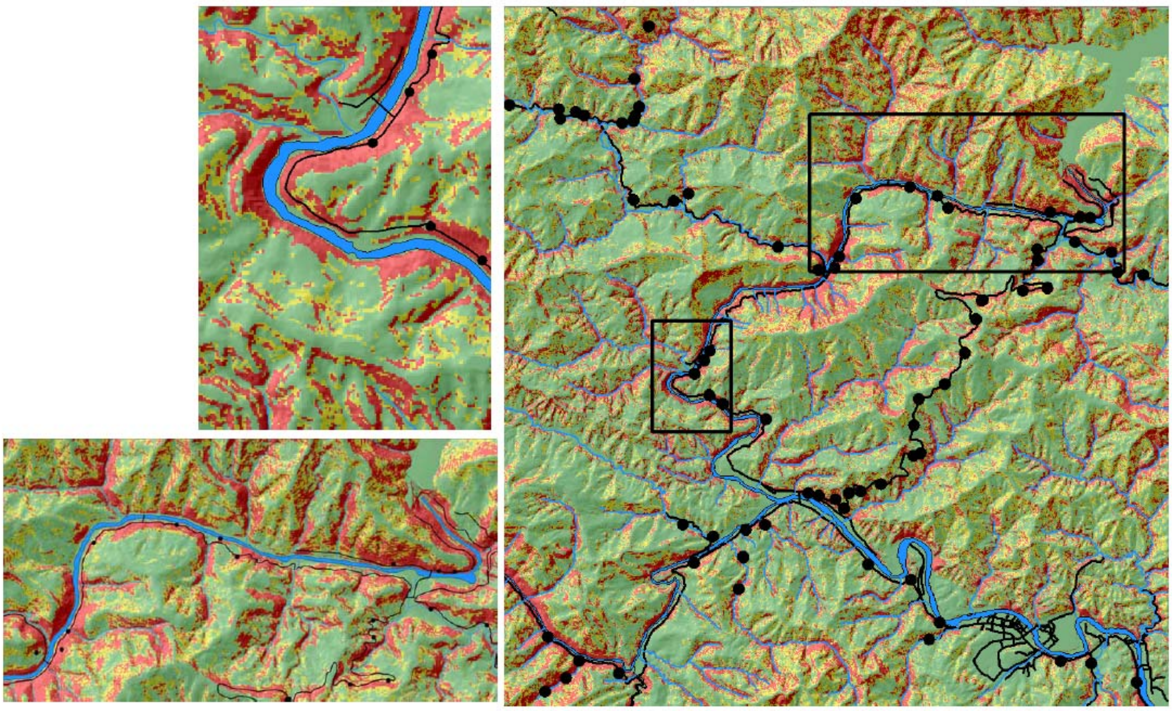


Figure 4.8: Example of an initiation susceptibility map.

In the final susceptibility map we also overlaid the existing landslides, with differentiation between the field checked landslides (available only as points and which will be displayed according to their types) and the photo-interpreted landslides which are shown as polygons with hatching and differentiated according to scarp and body, and to certain and less certain landslides.

We checked the relation with the existing landslide points. They are quite good. However, we don't want to use only the statistical relation as we saw that many of the landslide points might not be at the exact location, and sometimes the next pixel was classified as high.

4.4 Legend of the landslide susceptibility map

For the final susceptibility maps, we need to design a legend, consisting of the following classes:

Legend classes	Explanation	Percentage of all landslides	Landslide density
Existing landslides	With suffixes indicate: - Type of landslide - Activity (relative age) - Scarp/accumulation areas		
High susceptibility	Limited areas that should be avoided in spatial planning due to their high landslide occurrence	>75%	
Moderate susceptibility		Max 25%	
Low susceptibility	As large as possible area, that have no or only a few landslides. Can be considered safe for spatial planning	< 2 %	
Not susceptible	Areas with certainty that no landslides are likely to occur	0 for certain	

Table 4.2: Legend classes of the landslide susceptibility map

- The percentage of all landslides within the map sheet. Ideally high susceptible areas should have at least 75% of all landslides, the moderate areas maximum 25 % and the low susceptible areas should have less than 2 % of all landslides. We should define this for all the maps sheets, so that these rules apply everywhere.
- The density of landslides per unit area (km^2). The legend of the final map should explain the expected landslide density for each of the legend units. The highest susceptibility class should also have the highest density. We probably cannot use fixed thresholds for this for the entire country, as there are areas that have a much higher landslide density than others. If we would then use fixed landslide densities, some map sheets might not get more than moderate hazard zones. Anyway, this point should be evaluated still.
- The landslide types. Initially we will make different landslide susceptibilities for different landslide types, as they might be related to different combinations of causal factors. For instance: different susceptibility map for debris flows, deap seated landslides, and surficial landslides. We can also differentiate the initiation and accumulation susceptibility. If we do that the susceptibility classes would have a code indicating the type of landslide, and the erosion/accumulation part.

Table 4.3 gives the legend classes for the final susceptibility map with the explanation in Vietnamese as well.

Legend classes of the landslide susceptibility map:

Khoanh vùng hiện trạng	Cấp phân vùng quy hoạch	Percentage of all the landslides in the province	Landslide probability (which is related to the percentage of the area that might be affected by landslides)	Quy hoạch dân cư
Rất cao	I	Depends, <5 %	100%	Không thể sinh sống được, cần di dời dân cư Very High Susceptibility. Can not habitable, residential relocation is needed There is evidence of existing landslide activity which makes this very problematic.This will contain the hotspots required for further analysis
Cao	II	80%	>20 % or 1 landslide /km2	Có thể sinh sống được nếu có các biện pháp phòng tránh thỏa đáng High susceptibility. There could be settlement if the proper precautions are taken. Also this class can contain hotspot areas, that are very dangerous but cannot be evacuated. This class will contain areas with historical landslides that are potentially dangerous but where measures can be taken to reduce the risk.
Trung bình	III	15%	<1 % or 1 landslide per 10 km2	Sinh sống được, chú ý thực hiện các biện pháp phòng tránh giảm thiểu hậu quả Moderate susceptibiity. There are sparse incidences of landslides, and care should be taken when making new developments. In some cases, attention should be given to implement preventive measures to minimize the consequences.
Thấp	IV	<1%	<0.1 % of the area still can have landslides Or 1 landslide per 50 km2	Sinh sống được, cần chú ý các biện pháp công trình khi tiến hành các công trình dân dụng Low susceptibility. The conditions are such that landslides are very unlikely. A few isolated landslides might occur. The areas is safe for settlements. In some case simple structural measures should be applied for protection.
Không xảy ra	V	0	0%	Sinh sống ổn định Absent. The conditions are such that no landslides can occur in these areas.

Table 4.3: Legend classes of the landslide susceptibility map, with explanation in Vietnamese

4.5 Landslide runout assessment

We then extracted the high susceptible areas, and used these in a regional scale run-out model (Flow-R developed by the University of Lausanne). From this we generated a map showing run-out probability, which we also classified into high, moderate and low.

Flow-R (Flow path assessment of gravitational hazards at a Regional scale) is a distributed empirical model for regional susceptibility assessments of debris flows, developed at the University of Lausanne. It was successfully applied to different case studies in various countries.

The model was also found relevant to assess other natural hazards such as rockfall or snow avalanches. It allows for automatic source area delineation and for the assessment of the propagation extent. The choices of the datasets and the algorithms are open to the user, which makes it compliant for various applications and dataset availability

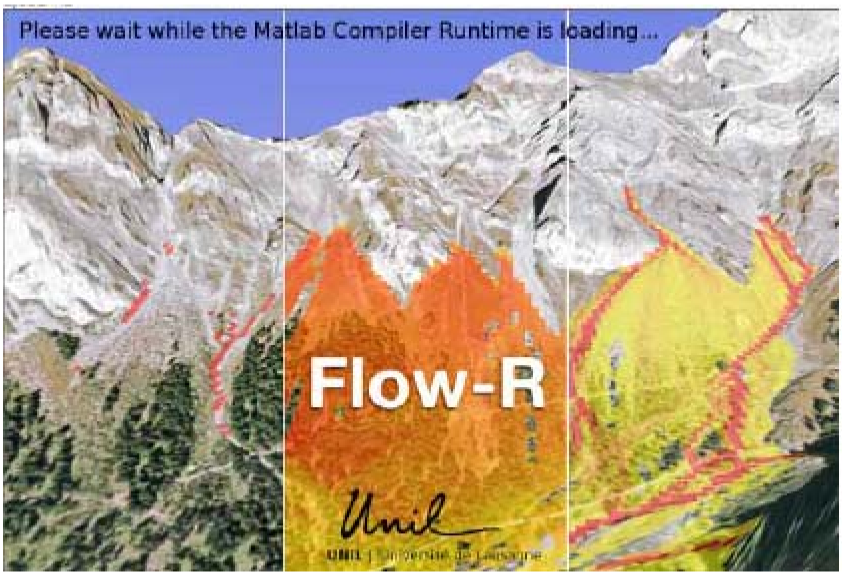


Figure 4.9 : Openings screen of the Flow-R software for regional scale runout modelling

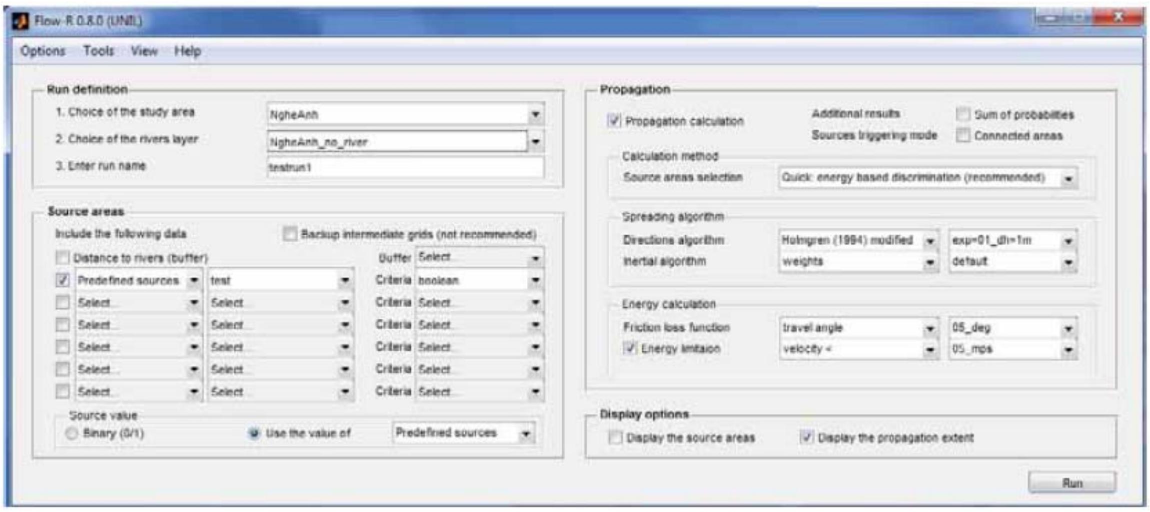


Figure 4.10 : Main input screen of the Flow-R software for regional scale runout modelling

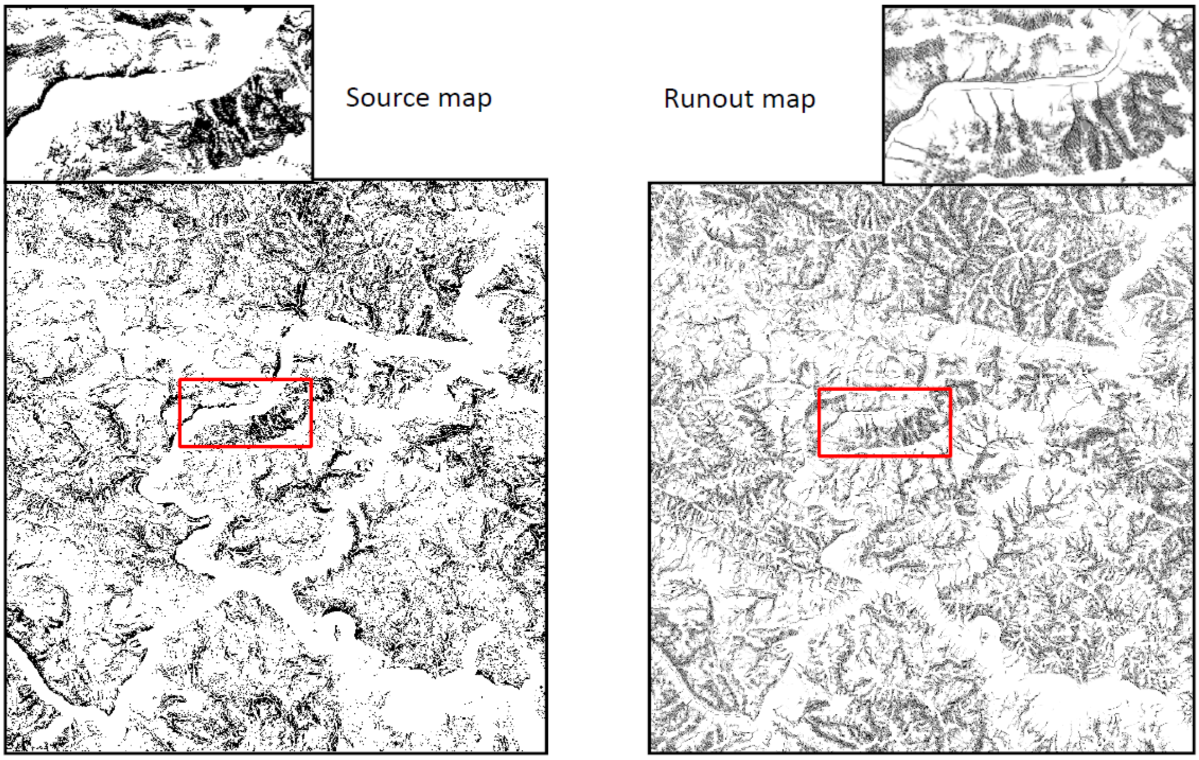


Figure 4.11: left: source map which was extracted from the highest class of the landslide initiation map. Right: runout extend map.

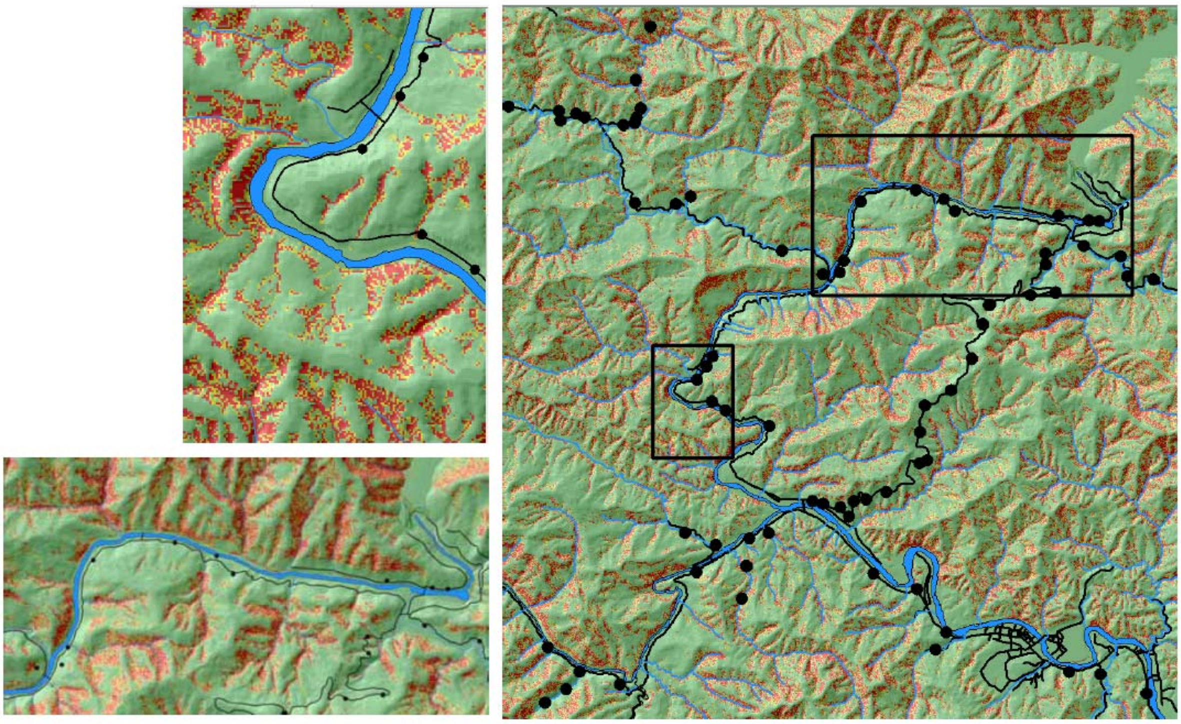


Figure 4.12: example of a landslide runout map.

4.6 Final Susceptibility map

The final susceptibility map was made by combining two individual maps: the initiation susceptibility map and the run-out susceptibility map

This combination was done using a two dimensional table:

		Initiation susceptibility		
Runout susceptibility		**low**	**Moderate**	**High**
	Low	**Low**	**Moderate**	**High**
	Moderate	**Moderate**	**Moderate**	**High**
	High	**High**	**High**	**High**

Then we used the final susceptibility map and overlaid it with the district and communes and calculated the area and the percentage of high, moderate and low susceptibility per administrative unit. We will use this information to display as bar charts or table next to the map.

Then we also crossed the final susceptibility map with the buildings, roads, and agricultural fields and calculated the number, length or area per administrative unit, exposed to high , moderate and low susceptibility.

Majority filter

In order to avoid that the final susceptibility map has a large number of individual pixels with different susceptibility levels, it is advisable to apply a majority filter to the susceptibility map for a few times. The majority filter select for a group of 3 by 3 cells, the majority of the classes in the 9 cells and assigns this to the central cell. When this is done a few times isolated pixels with different susceptibility classes than the surroundings are removed.

Iterative process

Generation of a susceptibility map is an iterative process. It needs to be done in several stages:

- Generate an initial map
- Compare the results with the existing landslide pattern
- If there are sufficient landslides, generate a success rate curve
- Analyze where the resulting susceptibility map shows anomalies, and which contributing factors might be responsible for that.
- Adjust either the number of contributing factors, or combine some of the factors to make them more focused, or adjust the weighting of the contributing factors;
- Generate a new version of the susceptibility map
- Repeat the procedure

How do the maps fit

One of the important aspects to keep in mind when doing such landslide susceptibility assessment for neighbouring map sheets is to check carefully whether the susceptibility levels of two adjacent map sheet are compatible. This requires that the teams working on the two adjacent map sheets agree on the factors used and on the weighting, and several adjustments have to be made in order to ascertain that they match.

For which period is the susceptibility map valid? This is an important point for discussion…

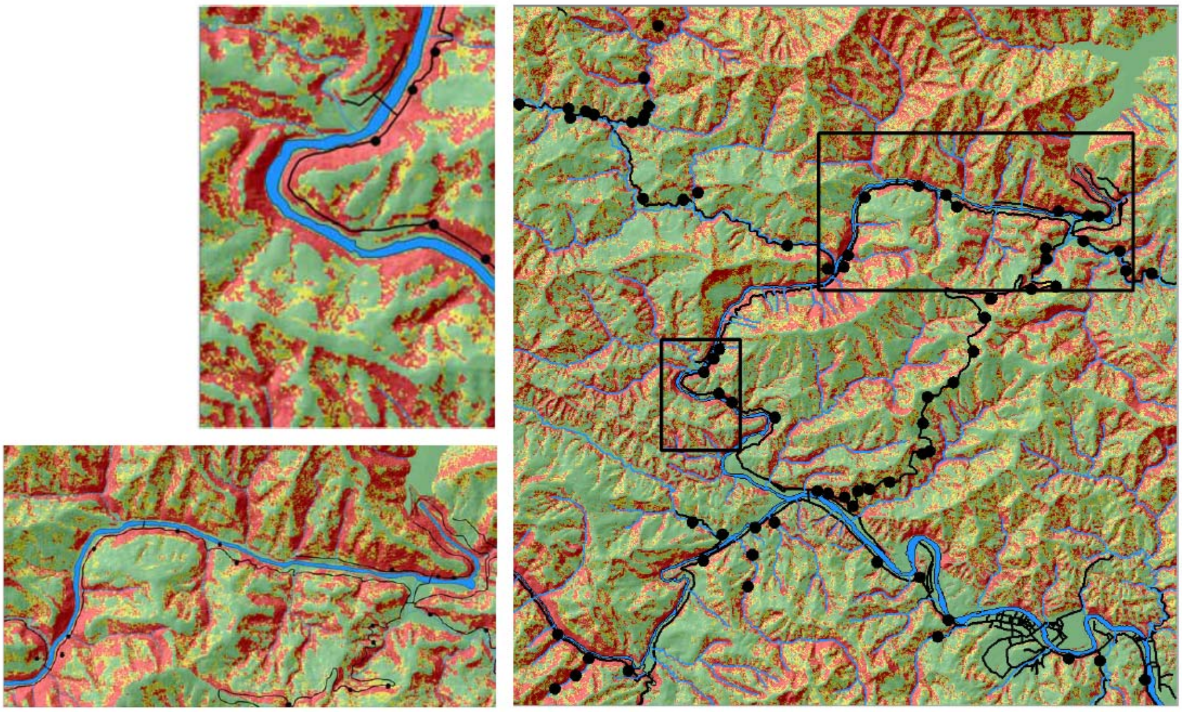


Figure 4.13: example of a the final landslide susceptibility map, which is a combination of the initiation susceptibility and the runout susceptibility maps..

4.7 Validation of the final susceptibility map

Once the landslide susceptibility maps are generated they have to be validated in one way or another. There are several ways to validate the results:

- The simplest way of validation is to analyse the susceptibility values for the existing landslides. In the case that the landslides are represented as points, the landslide point map can be opened as a table in ILWIS, and using the command Susceptibility:= mapvalue(susceptibility,coordinate), the susceptibility values are obtained for each landslide. They can then be plotted or arranged from high to low values.
- Another approach is to use the same operation after classification of the susceptibility map into the three classes. With this method it is possible to directly obtain the number of landslides in the various susceptibility classes, and also to calculate which percentage of the landslides is in the high, moderate and low classes.
- The third option is to generate so-called **success rate curves**. A success rate curve is made by overlaying the susceptibility map (before classification) with the landslide inventory map. The percentage of the susceptibility map with values ranging from the highest to the lowest is plotted on the X-Axis, and the percentage of the number of landslides on the Y-axis. The steeper the curve is and the more it deviates from the diagonal, the better the prediction is.

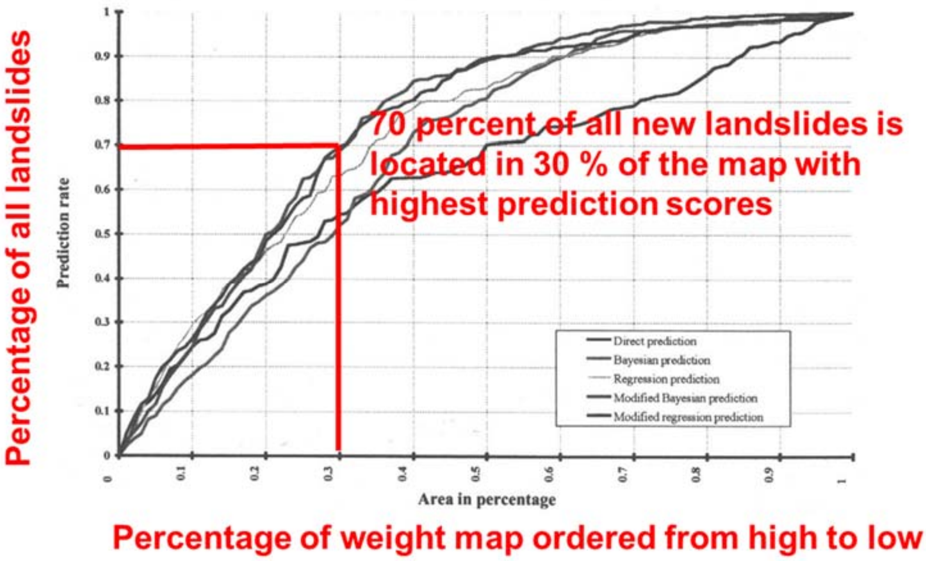
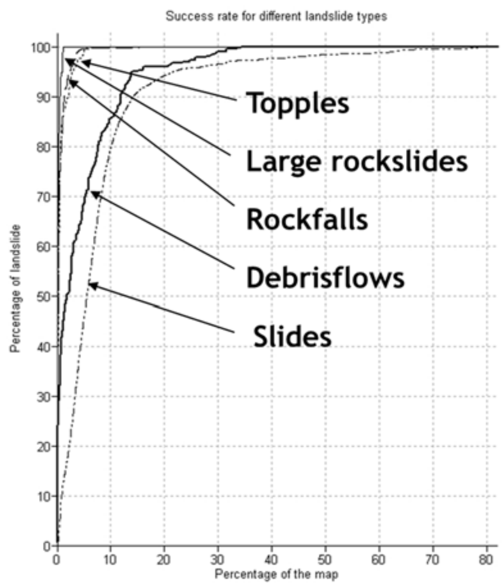


Figure 4.14: Success rate curve for the validation of the landslide susceptibility map.

- When the validation is done with the same dataset that was used in a statistical model, we call the resulting curve a success rate curve, because what is tested is only whether the model explains the landslides that were used to make it. When you use a landslide data set that is different from the data set used for making the model, we can actually test the prediction capability of the map, and the resulting curve is called a **prediction rate curve**. The two sets are called training data set and test data sets. If the number of landslides in a study area is large enough, it is common to separate the dataset into 60 percent (training data set) and 40% (test data set).
- Ideally you would use a dataset from another period than the test dataset, so that one can check whether a susceptibility map is capable of predicting new landslides. However, care should be taken here, as the conditioning factors (in particular land cover, or roads) might have changed which then makes that the prediction rate will be much less than the success rate.
- When different susceptibility maps have been generated for different landslide types, it is also possible to generate success rate curves for the various maps (See Figure). It may be that for certain types of landslides there is a much better prediction than for others. A better prediction means that a smaller part of the susceptibility map with the highest values contains most of the landslides, In order words that the majority of the landslides is within the highest susceptibility values.
- Success rate curves can also be used to classify the susceptibility maps into the required number of classes. The curves can be used to



select predefined levels for the percentage of the landslides and the corresponding area of the map. This is illustrated in the table below.

	Weights	Percentage landslides	Percentage area
High	>0.4	90 %	5.2 %
Mod	0.2-0.4	9 %	2.6 %
Low	<0.2	1 %	91.7 %

Table 4.4: Example of a table showing the classification of a susceptibility map based on the percentage of landslides and the percentage of the area.

The landslide validation methods explained above should not be taken as absolute. As is shown in the map below, it often occurs that the historical landslide points are actually in low susceptibility zones, but in the immediate vicinity of high susceptibility zones. This is not shown when making the success rate curves. So in practice it is also equally important to carefully check the susceptibility map where the landslide points are overlain.

It is possible that the landslide points might not be exactly located in the right place, which may account for the apparent low correlation with high susceptibility classes.

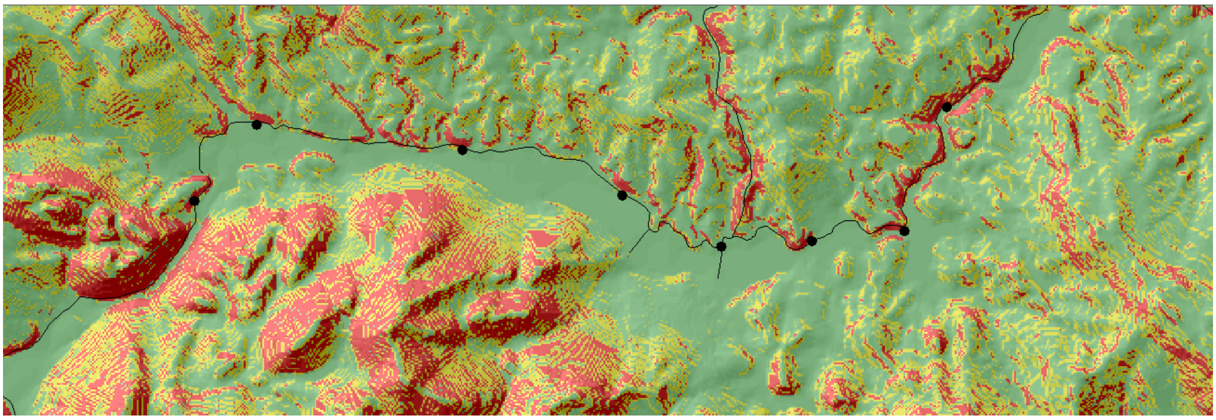
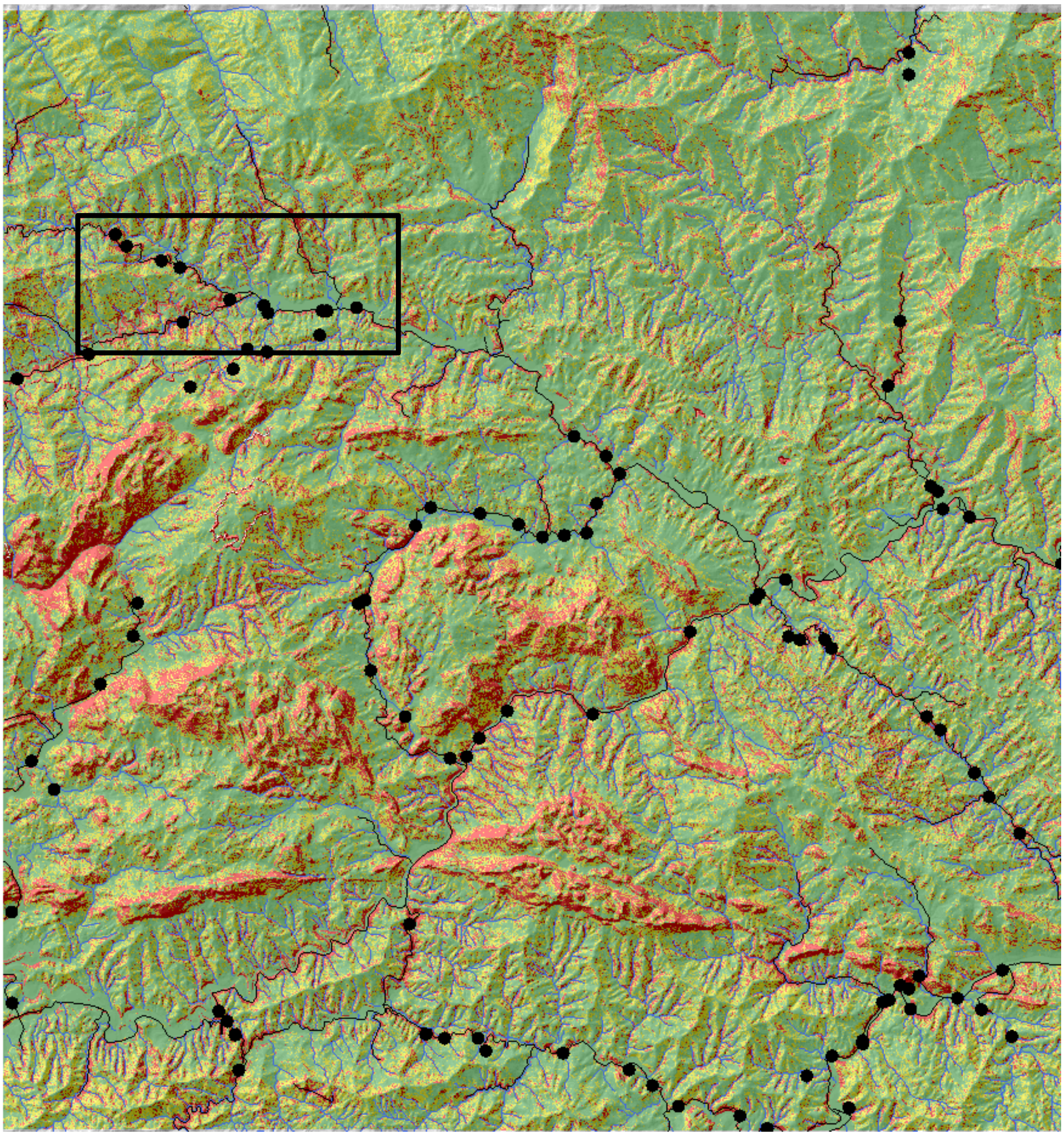


Figure 4.15: Example showing that the actual landslide points might be in low suwceptibility zones but in the direct surrounding of high susceptibility zones.

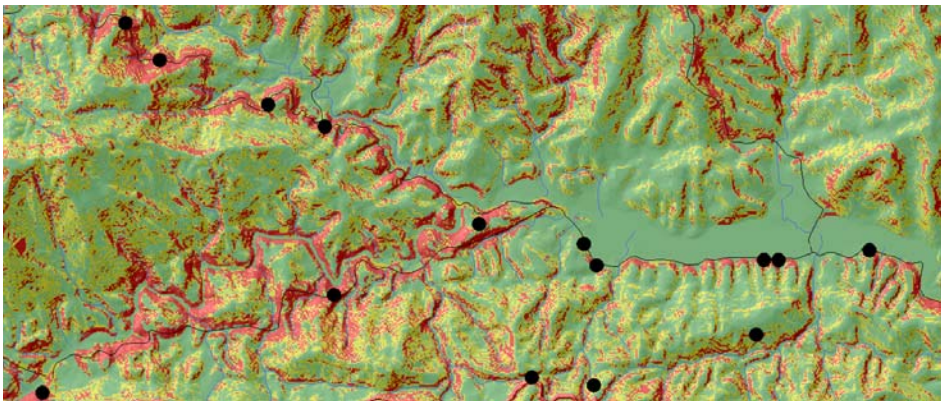
- **It is extremely important that the resulting landslide susceptibility maps is carefully reviewed by a group of landslide experts that have field knowledge and have visited the study area.**
- **In a workshop setting they should discuss which areas in the landslide map do not seem to represent the best susceptibility classes, and discuss the reasons for that (e.g. wrong classification of geological units).**

In the following pages the resulting susceptibility maps are presented for the three test maps. These maps should be carefully discussed with experts in a workshop in Hanoi, and the deficiencies should be identified. Also the input data should be reviewed, and the relative weighting of the maps.

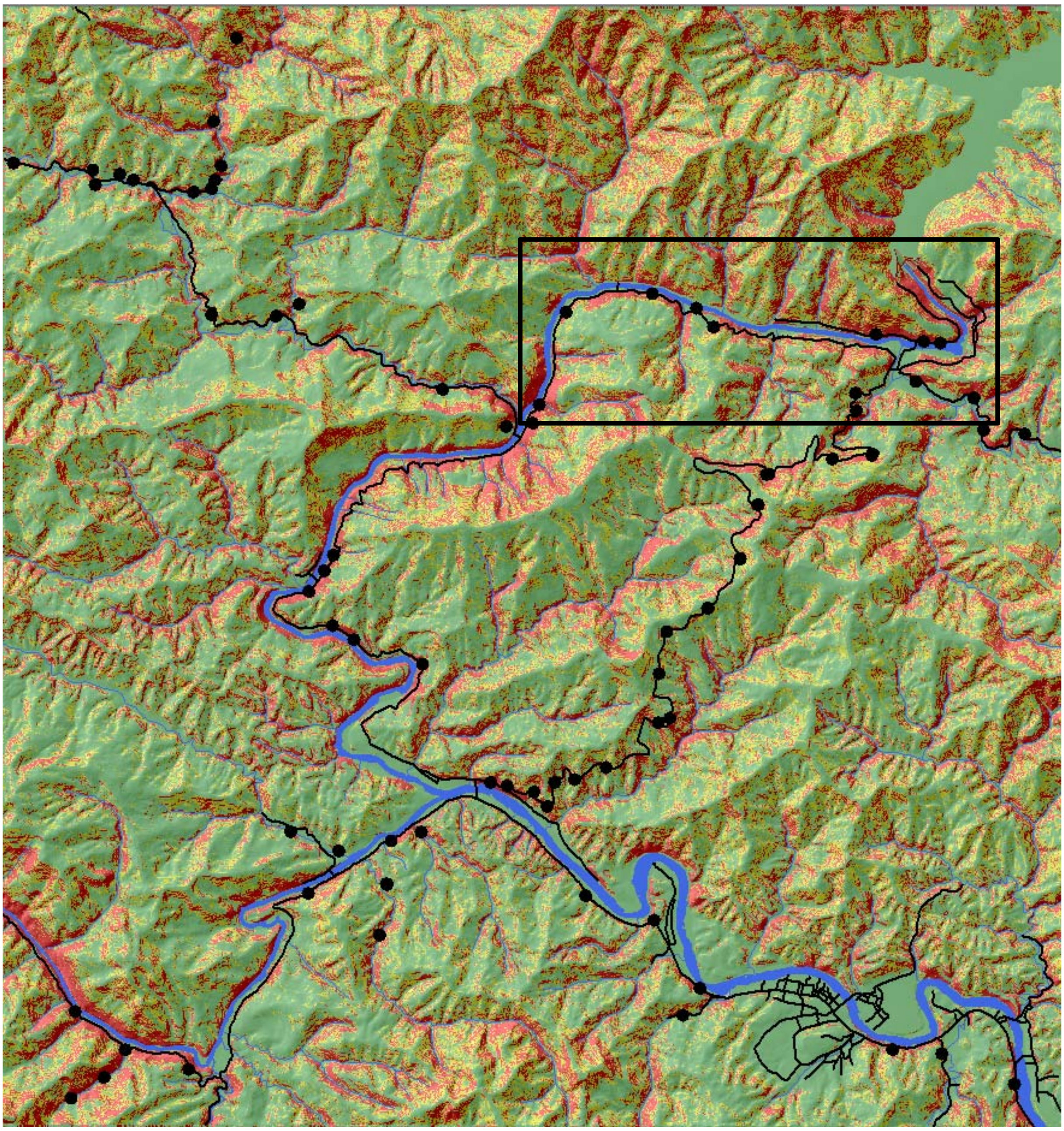
4.1 Maps sheet Thanh Hao Province



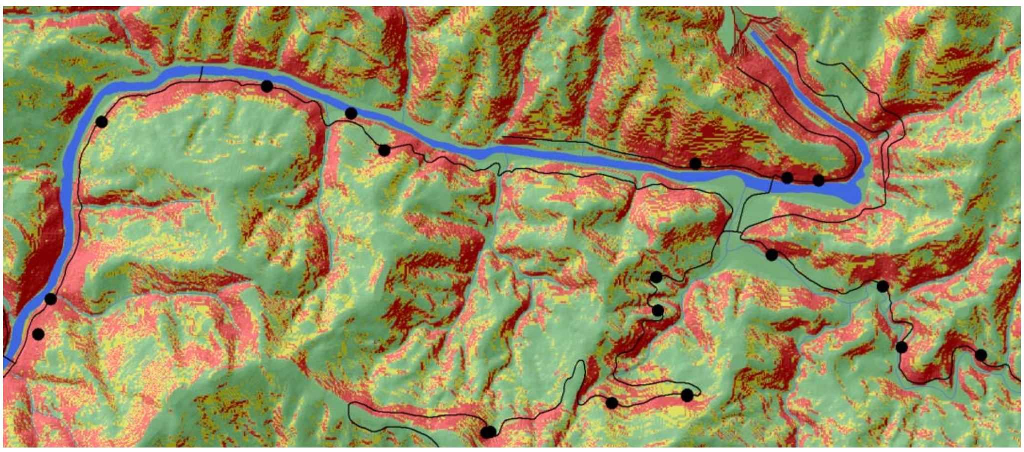
Detail:



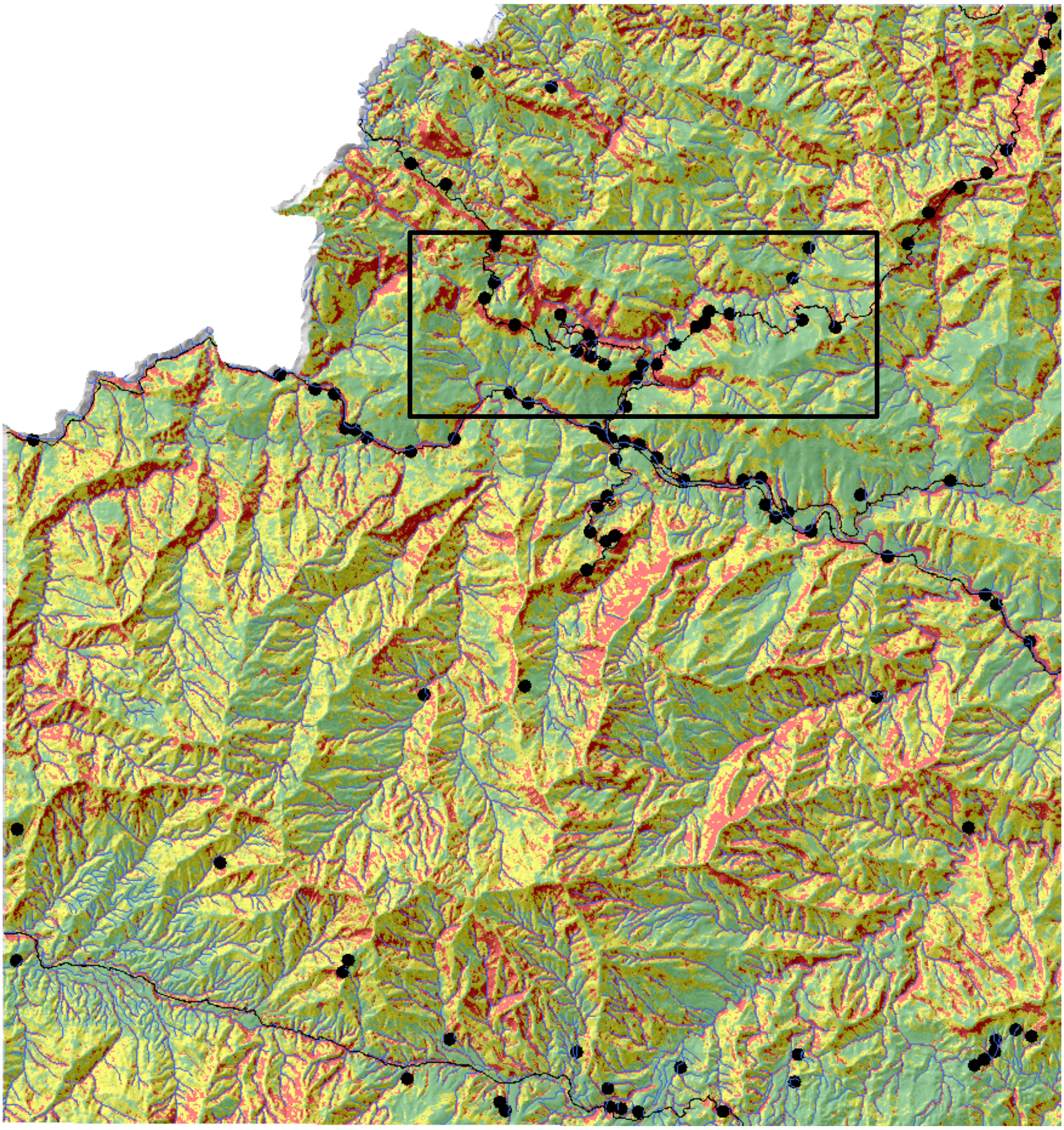
4.2 Map Sheet Nghe Anh Province 1



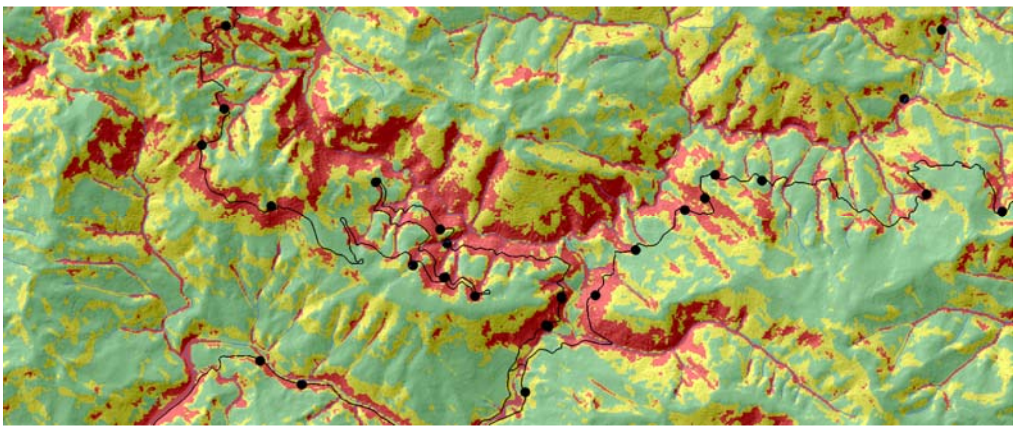
Detail:



4.3 Map Sheet Nghe Anh Province 1



Detail:



5. Production of the cartographic map products

One of the important components in the project is the production of landslide and inventory maps. Therefore also recommendations are given here with respect to the cartographic design of the maps. This section will present the resulting maps and the way these have been designed.

5.1 Map Layout

The map is A1 format (84.1 cm width by 59.4 cm height) with the actual map area with a mapping scale of 1:50.000 this represents a map size of 52.24 cm (X-Direction) and 55.4 cm (Y-direction).

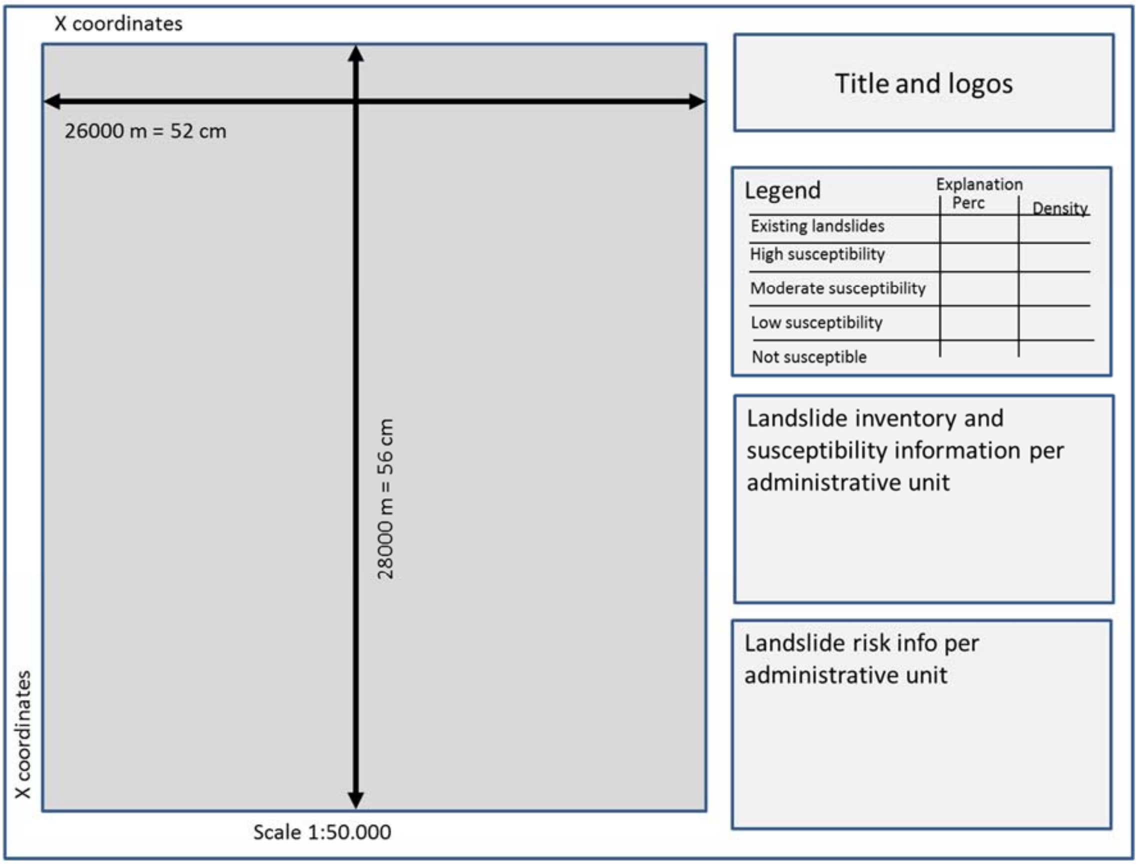


Figure 5.1: initial layout of the susceptibility maps

The cartographic mapping is done using ArcMap, and a standard template has been developed for the susceptibility maps that will be produced later.

The susceptibility map contains the following data layers, in the order from below to top:

1 The lowest layer is a hillshading images generated from the Digital Elevation Model in ILWIS. This is displayed in greytones.
2 On top of that the final landslide susceptibility map is shown, with three legend classes. The map is shown with a transparency.

3 Then the hillshading image is displayed again, but with a much higher transparency level, in order to make sure that the terrain is wll portrayed which enhances the readability of the map.

4 Index contour lines of 100 meters were derived from the DEM, and automatic labels were generated in ArcMap, which were later manually edited.

5 The other contour lines (10 meter contour interval) are displayed as very thin grey lines.

6 Drainage lines are indicated either as single blue lines (small rivers) or as blue polygons (main rivers).

7 Roads are displayed twice. The first time as balck lines and the second time as white lines, so that they fall within the black ones.

8 Buildings are displayed as black polygons, and settlements are also indicated in an orange colour.

9 Commune boundaries are indicated as dotted thick lines and the district boundaries are closed thick lines.

10 A limited number of names of the districts, communes and the settlements is indicated in the map

11 The historical landslides are indicated as points (as we did not have historical polygon based ones) according to the main landslide types;

12 The older landslides that are mapped through photo-interpretation are added as polygons with hatching, making differentiation between scarp and body and between clear and unclear landslides

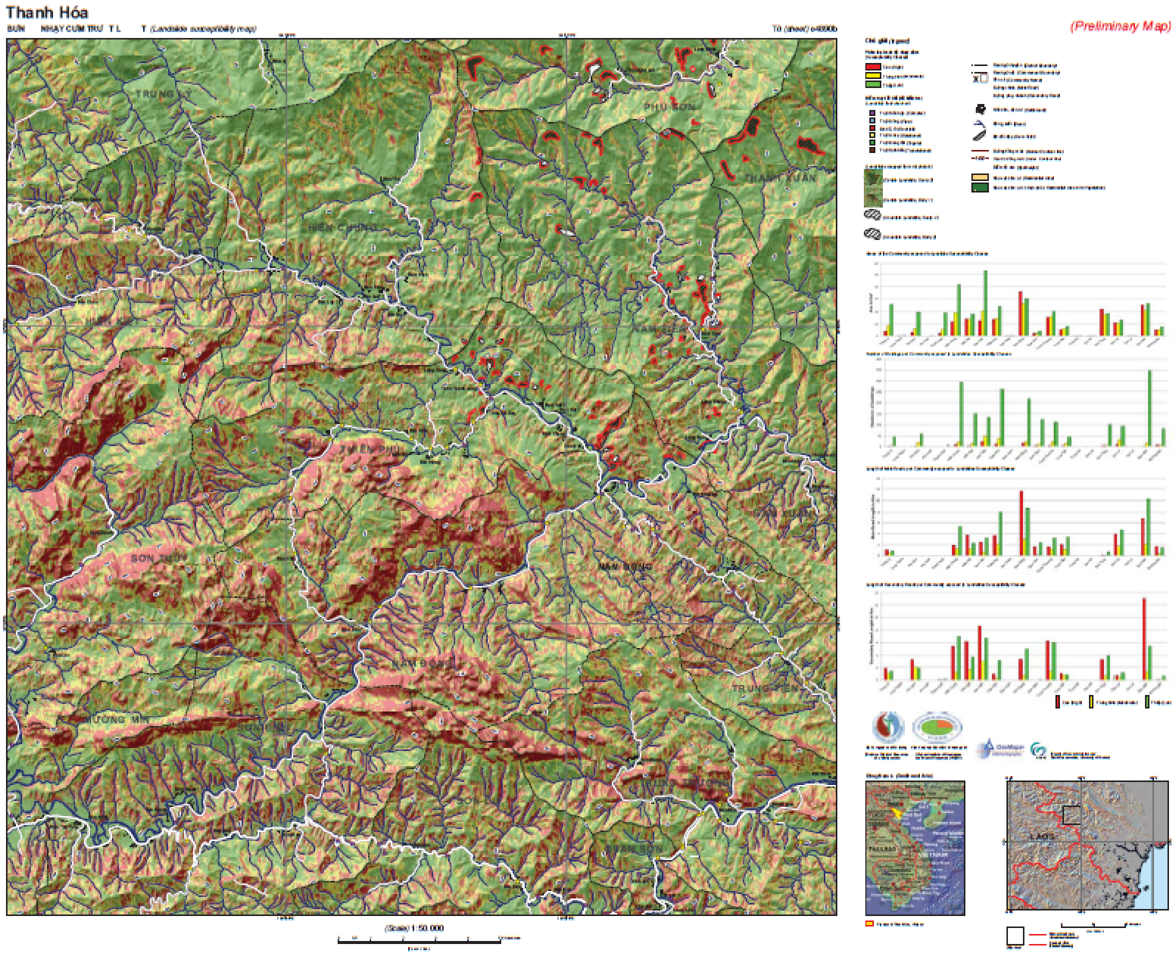


Figure 5.2: Example of the final susceptibility map for one of the mapsheets.

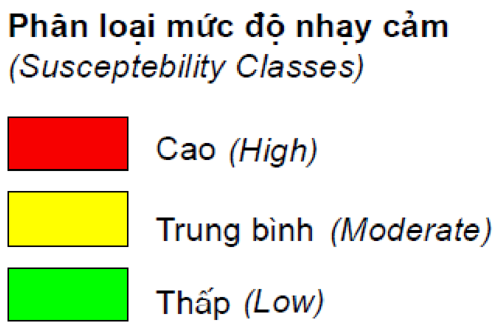
5.2 Legend

The legend of the susceptibility map contains a number of components, related to: the susceptibility classes, the historical landslides, the old photo-interpreted landslides, and the topography. In this section the various components will be reviewed.

Figure 5.3: Proposed legend of the landslide susceptibility maps.

Landslide susceptibility classes

The landslide susceptibility is displayed in a limited number of classes that should also have a clear description of what the meaning is of these units. They form the combination of the initiation susceptibility and the runout susceptibility. For a more elaborated version of the legend it would also be possible to incorporate the different landslide types, as well as the initiation susceptibility levels.

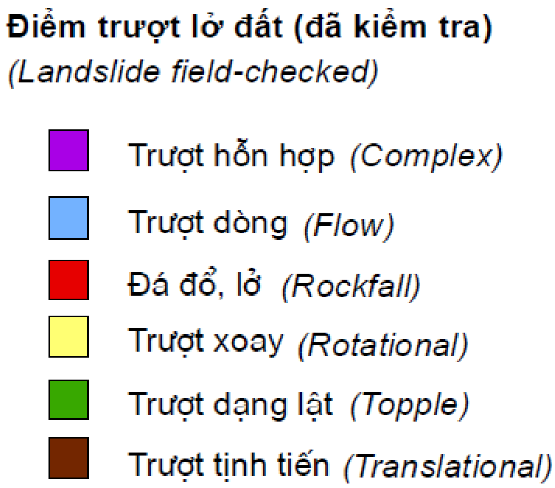


The explanation of the susceptibility levels was given in section 4.2

If more landslide information is available per map sheet it would also be useful to display per legend class: the number of landslides within the class, the percentage of the class occupied by landslides (only possible if landslides are mapped as polygons) and the percentage of the susceptibility class for the entire map sheet.

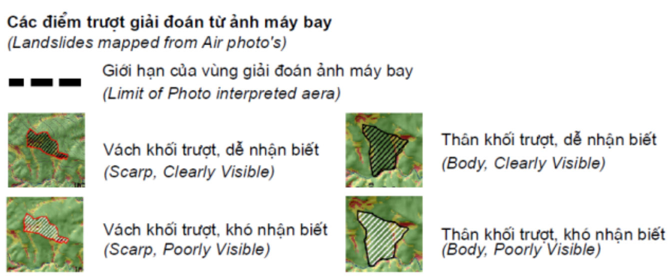
Historical landslides mapped mapped in the field

The historical landslides are plotted on the map as points (as we do not have polygon information for them). We have decided here to display them according to the type of landslide, as this was the only coherent attribute available for the historical landslides. If more information is available it would also be possible to indicate the date of the landslide as text next to the landslide point.



Landslides mapped through image interpretation

The old landslides mapped through stereo-image interpretation are displayed as polygons, with hatching, that indicates the scarp or body of the landslides, and whether the landslide can be clearly recognized on the image or not. In the current version of the maps we only have a small area covered through image interpretation. This was because it took too much time for the photo-interpretation of the entire maps, and also the interpretation of three VIGMR staff was too uncertain due to their limited experience in image interpretation. Therefore an ITC expert spend a number of days on photo-



interpretation but could cover only a small portion of two of the three maps. This is clearly the major bottleneck in the production of the maps for the rest of the country, as explained earlier in the chapter on landslide inventory mapping.

Topographical information

The susceptibility maps contains a number of topographic elements that allow the users to read the susceptibility levels in relation with roads, rivers, settlements, communes and districts.

These are the standard type of objects that are shown on such maps. The buildings are displayed as individual polygons, even though they are very small, because it is very important to relate the susceptibility map with the existing buildings and other infrastructure. Because building information was not available for the entire area, we also decided to include the settlement areas as a separate unit.

5.3 Data sources

It is also important to indicate on the map the sources of the data that were used in the generation of the susceptibility map. The information displayed now on the example maps is probably still quite incomplete and needs to be updated. Also it is important to explain in this section how the landslide information was obtained.

Nguồn tài liệu (Source):

Bản đồ Địa hình: Tổng Công ty Tài nguyên và Môi Trường Việt Nam
Topographic maps: Vietnam Natural Resources and Environment Corporation

Bản đồ Sử dụng đất: Viện Khoa học Địa chất và Khoáng sản
Landuse map: Vietnam Institute of Geosciences and Mineral Resources

Bản đồ Thảm phủ: Viện Khoa học Địa chất và Khoáng sản
Landcover map: Vietnam Institute of Geosciences and Mineral Resources

Bản đồ Địa chất: Tổng cục Địa chất và Khoáng sản
Geological map: General Department of Geology and Mineral of Vietnam

Nguồn ảnh Viễn thám: Google Earth
Satellite image: Google Earth

Nguồn ảnh máy bay: Tổng Công ty Tài nguyên và Môi trường (Độ phân giải: 1m, Tỷ lệ: 1:33.000)
Air photo: Vietnam Natural Resources and Environment Corporation
(Resolution: 1m, Scale: 1:33.000)

Hệ Tọa độ: VN2000 - 105 múi 3
Project: VN 2000 - 105 zone 3 degree

Tác giả: (Authors:) C.J. Cees van Westen, M.C.J. Michiel Damen, Koert Sijmons, Đỗ Minh Hiển, Trịnh Thành, Lưu Thanh Bình

5.4 Disclaimer

Đây là bản đồ phân vùng trượt lở đất được hoàn thành dựa trên các tài liệu đã thu thập bao gồm: Bản đồ Thảm phủ, Bản đồ Sử dụng đất, Bản đồ Địa chất.
Disclaimer: This is a preliminary map. The content of the Map is based on partially incomplete and incorrect data. Further data collection is required in teams of Landslide Inventory, Geological and Landuse data.

Given the many problems encountered with the available data, in particular with

Phiên bản thứ nhất
(Preliminary Map)

the existing landslide inventory, the geological maps and the landuse maps, the current versions of the landslide susceptibility maps are only preliminary ones. These should not be presented yet to the end users as the final maps. Therefore we have included these statements on the maps.

5.5 Location maps

The susceptibility maps also should contain proper location maps of the mapsheets. These could be done in the way illustrated below, or could also be done following the index maps of the topographic maps, so showing all topgraphic maps, with the one portrayed in colour, together with the code of the map.

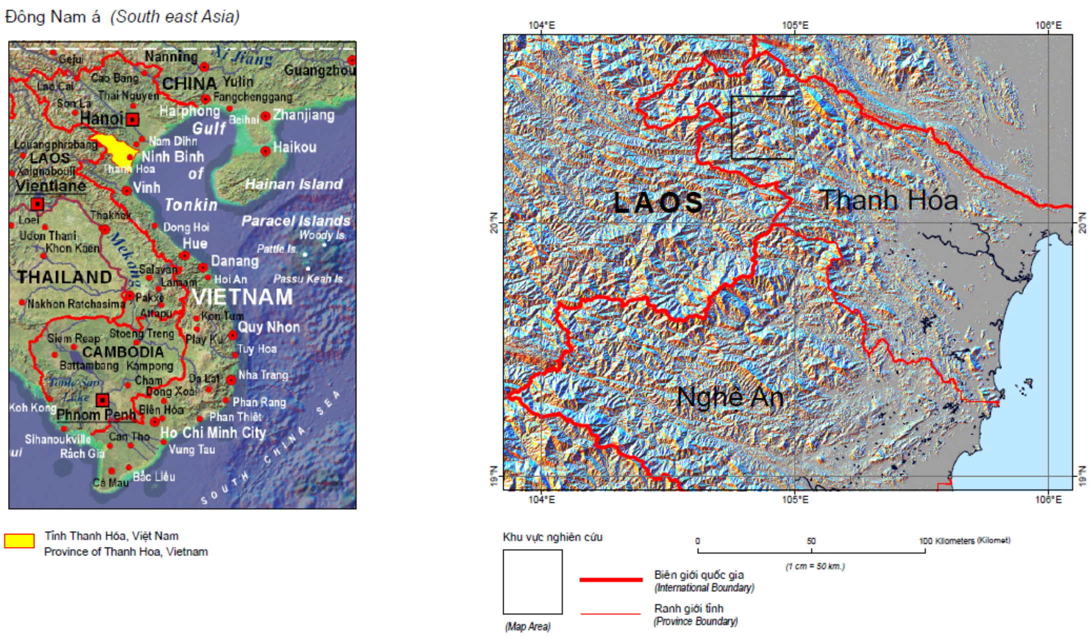


Figure 5.4: Example of the location maps on the susceptibility map sheets.

5.6 Susceptibility data per administrative unit

In the susceptibility map there is also a part reserved for graphs that represent the susceptibility information per administrative unit. In the GIS the susceptibility map is overlain with the communes map, and for each commune the area of the high, moderate and low susceptibility is calculated. This is useful for local authorities to compare the susceptibility levels for the various administrative units. It is also possible to represent this data in the form of percentages of the area of the communes, but the actual area is perhaps better.

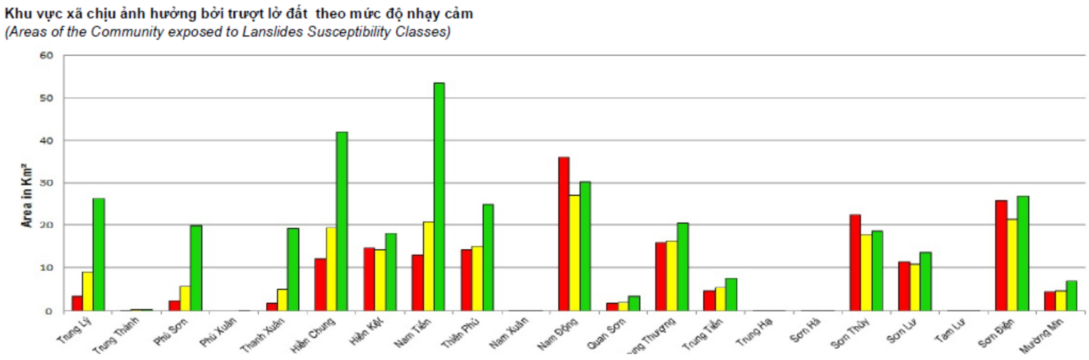


Figure 5.5: Exposed area per community for the various susceptibility classes.

5.7 Landslide exposure and risk information

Another set of graphs on the landslide susceptibility maps is used to represent the exposure information: for buildings, main roads, and secondary roads. The exposure information is obtained through two map overlays. First the landslide susceptibility map is overlain with the elements-at-risk map (either buildings, main roads or secondary roads, but also other elements-at-risk could be used like agricultural land).

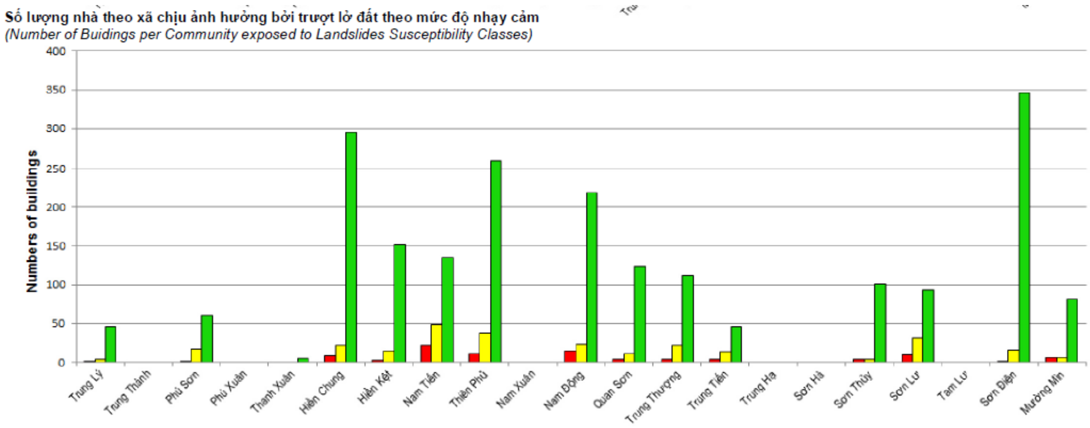


Figure 5.6: Exposure information showing the number of exposed buildings per administrative units for the three susceptibility classes.

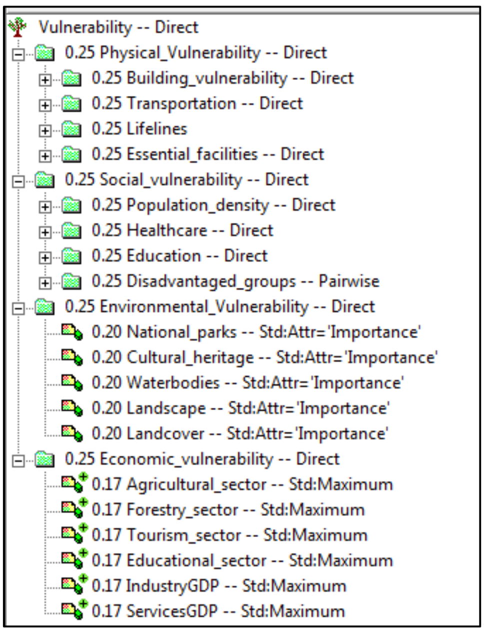
Unfortunately there is not enough information to carry out a risk assessment at this moment, as we do not have enough temporal landslide information to be able to define return periods of triggering events, nor do we have intensity information for the landslides, or the spatial probability for the susceptibility classes. We currently also do not have a proper classification of the elements-at-risk (especially the buildings) in terms of material types or occupancy types in order to be able to do a vulnerability assessment. We also do not have vulnerability curves for the elements-at-risk available at this moment.

Therefore the best that can be done now is to represent the risk in the most simple terms: exposure. The calculation of the exposed number of buildings per administrative unit, or the length of the exposed roads is a useful first indication that can be used in the planning of priorities for risk reduction measures, and for emergency preparedness. Since we do not have a clear picture yet of how many landslides may be generated within a given period of time, we are not able to express the risk in monetary values. Nor do we have enough population information at this moment to express the population risk. However, population distribution modelling could be carried out when we have the population data per commune and the occupancy types and floorspaces of the buildings within the communes.

Figure 5.7: Exposure information for roads.

It would also be possible then to generate qualitative risk maps using Spatial Multi-Criteria Evaluation per community where two individual criteria trees could be made: one for the hazards and one for the vulnerability.

The vulnerability criteria tree would contain the subdivision into physical vulnerability, social vulnerability, environmental vulnerability and economic vulnerability. For each of these main groups, subgroups could be made, and eventually a set of indicator maps, that represent information at the commune level or more detailed.



The hazard criteria tree could then be made by using as main groups: old landslides, historical events, and susceptibility classes. The hazard index map and the vulnerability index map are then combined using a two-dimensional table. This would require the collection of more thematic data, and it is the question whether there are resources for that in the framework of this project.

6. Conclusions

After returning to Vietnam VIGMR staff have also generated two other susceptibility maps for the districts of Cho Bon and Pac Nam in Bac Kan Province. Also in several other northern provinces landslide susceptibility mapping will be carried out in 2014.

Figure 6.1: Example of the new susceptibility map produced for Pac Nam district in Bac Kan Province.

The current maps are still preliminary because:

- The landslide inventories are still incomplete and predominantly have landslide along the roads. Landslides on natural slopes should be mapped using image interpretation;
- Several of the factor maps are very problematic: lithological map, fault map and land cover map. These maps should be improved using image interpretation. Better estimations should be made of the relative importance of the different combinations;
- Susceptibility maps should be generated using a combination of statistical analysis and expert based spatial multi-criteria evaluation
- Separate susceptibility analysis needs to be done for:
    - Cutslopes
    - Natural slopes:
        - Landslides, rock falls, debris flows.
- Runout analysis should only be done for debrisflow related events;
- Landslide susceptibility maps should be evaluated by a team of experts, consisting of the staff that made the map, the field geologist that carried out the field investigations for the map sheet, representatives from the Flood and Storm Control committee, and the project coordinator. Based on these discussions the maps should be updated.
- Susceptibility maps should be validated using the existing landslide inventory, and the legend classes should be used in a uniform way, representing the change of a landslides (percentage of all landslides happening in the legend class) and the landslide density.

- Once more information is available on the landslide database collected in the field, and landslide inventories collected from image interpretation, and improved factor maps, new version of the susceptibility maps should be generated.
- The susceptibility maps should be regularly updated. For instance once every 5 years, or more if major changes occur within an area.
- The susceptibility maps should be made available through a web-GIS.

Annexes:

As annexes to these guidelines a number of examples of landslide guidelines are presented from different countries. It is clear that these cannot be simply adopted in Vietnam, as it has very different characteristics in terms of available data, landslide abundance and triggering factors, and environmental setting.