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SafeLand

Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies

7th Framework Programme
Cooperation Theme 6 Environment (including climate change)
Sub-Activity 6.1.3 Natural Hazards

Deliverable 7.5

GIS-based training package on landslide risk assessment

Work Package 7 – Dissemination of project results

Deliverable/Work Package Leader: ITC

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1			
2			

SUMMARY

This deliverable provides a series of case studies on various aspects related to the use of Geographic Information Systems (GIS) for landslide inventory mapping, landslide susceptibility, hazard, vulnerability and risk assessment. This training package contains 12 case studies from 4 different countries and using different scales of analysis. Each of the case studies comes with a complete dataset that users can download from the SafeLand website, or from the ITC ftp site. The case studies are based on an Open Source GIS and Image Processing software (ILWIS) which allows users to practice with the methods without the restriction of buying proprietary software. The software can also be downloaded together with the data files. The exercise descriptions are fully worked out and described, and each exercise can be carried out individually, without the need to follow them in a certain order.
The target group for this training package on GIS for landslide risk assessment conists of University students, PhD researchers and practioners on landslide hazard and risk assessment. Although the methods have been often simplified, they do go a good idea of what the capabilities are of using GIS for collection landslides inventories , monitoring changes through satellite images and Digital Elevation Models, analyse the initiation susceptibility of landslide using different methods (heuristic, statistical, physically based modelling), carry out run-out modelling, perform a rainfall threshold analysis, and perform both qualitative and quantitative risk assessments at different scales. Several of the case study areas that have been investigated in the SafeLand project (e.g. Barcelonnette in France, Nocera in Italy), and also in the two countries associated with the project (China and India).
The training materials can be used by individuals as personal training, or can be used in training courses. In that case a reference to the project and to the partner that generated the training package is required.

Note about contributors

The following organisations contributed to the work described in this deliverable:

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UNISA (S. Ferlisi, L. Cascini)

Other contributors:

CNRS (J.P. Mallet) who has provided all Barcelonnette site's data
UNISA (L. Cascini, S. Ferlisi, S. Cuomo) who provided the data on the Nocera case study area
CDUT (H. Runqiu, C.Tang, X. Fan) who provided the data on the Wenchuan area
UNIL (M. Jaboyedoff, P. Horton) for allowing us to use the FLOW-R software
University of Vienna (T. Glade, M. Kappes) for their input in the Barcelonnette case study

CONTENTS

1 INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

This SafeLand deliverable D7.5 "Development of a GIS-based training package on landslide risk assessment" is one of the components of Area 7 "Dissemination of project results" which aims to facilitate the validation and dissemination of results for all work packages. Specifically the results were used of Area 1 which focused on improving the knowledge on triggering mechanisms, processes and thresholds, including climate-related and anthropogenic triggers, and improving run-out models in landslide hazard assessment. Area 2 focused on harmonising quantitative risk assessment methodologies for different spatial scales, looking into uncertainties, vulnerability, landslide susceptibility and landslide frequency.

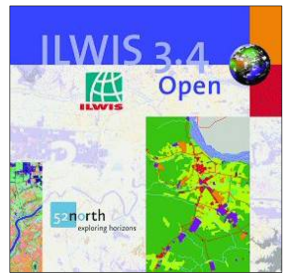
Mountain areas are exposed to a rapidly growing impact of disasters, due to increased vulnerability and climatic extremes. There is an urgent need to include the concepts of mountain risk management into planning, sustainable development and environmental impact assessment. One of the important components of mountain risk management is capacity building and training of researchers, experts and professionals working in many different tasks among the global 'living with risk' chain. The objective of this training package is to teach how to carry out risk assessment for landslide hazards. The cases are based on research results from the SafeLand project and other initiatives, such as the EC 6th Framework Marie Curie Initial Training Network "Mountain Risk", and the EC 7th Framework Marie Curie Initial Training Network "CHANGES" (http://www.changes-itn.eu)

1.2 OBJECTIVES

These case studies deal with the procedures to collect, analyse and evaluate spatial information for landslide hazard and risk assessment. The case studies will guide participants through the main components of risk assessment, on the basis of a series of case studies from different countries and at different scales of analysis.
The target group for this training package on GIS for landslide risk assessment conists of University students, PhD researchers and practioners on landslide hazard and risk assessment. Although the methods have been often simplified, they do go a good idea of what the capabilities are of using GIS for collection landslides inventories , monitoring changes through satellite images and Digital Elevation Models, analyse the initiation susceptibility of landslide using different methods (heuristic, statistical, physically based modelling), carry out run-out modelling, perform a rainfall threshold analysis, and perform both qualitative and quantitative risk assessments at different scales. Several of the case study areas that have been investigated in the SafeLand project (e.g. Barcelonnette in France, Nocera in Italy), and also in the two countries associated with the project (China and India).
The training materials can be used by individuals as personal training, or can be used in training courses. In that case a reference to the project and to the partner that generated the training package is required.

1.3 OPEN SOURCE SOFTWARE: ILWIS

In the development of the training package one of the driving aspects was that the exercises, the data and the software should be freely available for all interested to learn about the dissemination results of the SafeLand project. Therefore it was decided to base all the exercises on Open Source software. We decided to use the ILWIS software, as this is easy to learn, comprehensive and has an extensive set of tutorial material.



ILWIS is an acronym for the **Integrated Land and Water Information System**. It is a *Geographic Information System* (*GIS*) with *Image Processing* capabilities. ILWIS has been developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands up to release 3.3 in 2005. ILWIS comprises a complete package of image processing, spatial analysis and digital mapping. It is easy to learn and use; it has full on-line help, extensive tutorials for direct use in courses and 25 case studies of various disciplines (See www.itc.nl)

Since July 2007, ILWIS software is freely available ('as-is' and free of charge) as open source software (binaries and source code) under the 52°North initiative (GPL license). This software version is called ILWIS Open. ILWIS software can be downloaded for free from **52 North:** http://52north.org/

As a GIS package, ILWIS allows you to input, manage, analyze and present geo-graphical data. From the data you can generate information on the spatial and temporal patterns and processes on the earth surface.

For the exercise of chapter 8 we also use the **Flow-R** software, which has been developed by the University of Lausanne, Switzerland. Flow-R runs in a Matlab environment. Flow-R is a deterministic, empiric model working with regular grids. The model approaches the hazard in two steps: the identification of sources or initiation areas for the specific hazard and the calculation of the spreading/run-out of the initiated failed mass. The model Flow-R (Flow path assessment of gravitational hazards at a Regional scale) is currently available on request. Please contact Michel Jaboyedoff (michel.jaboyedoff@unil.ch) or Pascal Horton (pascal.horton@unil.ch) if you are interested in using the model.

1.4 THE DATA

The exercises in this training package each have their own GIS data which are zipped into a single file per exercise. The size of these datafiles varies between 83 Kb and 2.3 Gb, as can be seen in the table below. The datafile can be downloaded from:

- the SafeLand website (http://www.safeland-fp7.eu/) or
- ftp site (ftp://ftp.itc.nl/pub/westen/safeland).

Given the large size of some of the datafiles, the downloading might take a considerable amount of time. After downloading the data files should be unzipped in separate directories on the D or C drive (not on the desktop). The names of the datafiles are given in the table below. Only use the data that is meant for a particular exercise. Don't mix data from different exercises, as that will create problems in carrying out the exercises.

Chapter	Topic	Est. time hours	Data in file	Size of ZIP file
3	Earthquake induced landslide inventories	5	Exercise_Wenchuan.zip	481
4	Change analysis in earthquake area	6	Exercise_Beichuan.zip	164
5	Calculation of landslide- and lake volume using multi-temporal DEMs	8	Exercise_Vaiont.zip	6
6	Use of weights of evidence modeling for landslide susceptibility mapping	10	Exercise_Basilicata.zip	532
7	Source area modelling using a heuristic approach	4	Exercise_Barcelonnette_source.zip	2300
8	Run-out hazard analysis on a regional scale using the routing-spreading model	6	Exercise_Barcelonnette_runout.zip	39
9	Rainfall threshold analysis	3	Exercise_Nilgiri_thresholds.zip	0.5
10	Medium scale multi-hazard risk analysis for mass movements	6	Exercise_Barcelonnette_Risk.zip	527
11	Qualitative multi-hazard risk assessment using Spatial Multi Criteria Evaluation	4	Exercise_Barcelonnette_SMCE.zip	3.6
12	Quantitative risk assessment along a transportation corridor	4	Exercise_Nilgiri_QRA.zip	0.083
13	Quantitative multi-hazard risk assessment for floods, debrisflows and landslides	4	Exercise_Nocera.zip	42
	ILWIS 3.4 Software		**ILWIS 3.4 Open.zip**	17
	Flow-R			
	Total	**60 hours**		**4. 112 Gb**

Note:
The data for the exercises may only be used for educational purposes. It may not be used for other purposes unless written permission is obtained from the responsible person for the given data. In these cases, please contact:

- For the Barcelonnette data: Dr. J.P Malet (CNRS): jeanphilippe.malet@unistra.fr
- For the Nocera data: Dr. S. Ferlisi (UNISA): sferlisi@unisa.it
- For the other data: Dr. C.J. van Westen (westen@itc.nl)

1.5 USING THE EXERCISES IN TRAINING COURSES

The estimated time for doing the exercises is also indicated in the table above. These values are relative as it depends whether users have been working with the ILWIS software before, and how fast they carry out the exercises. In total it would take more than 60 hourse to carry out all the exercises in this training package.
This makes it a good tool to use in training course. Several of the case studies have also been used in training courses, as part of the SafeLand project and elsewhere.

One of the training course which was organised with support of the SafeLand project was the LARAM course. LARAM is an International School on "LAndslide Risk Assessment and Mitigation" that was founded on 12th April 2005 by the University of Salerno (www.laram.unisa.it). The School gives training to about 40 PhD students, selected every year, from the following fields: Civil Engineering, Environmental Engineering, Engineering Geology or other related studies. Since 2011 also a LARAM-ASIA course is organized. LARAM-ASIA is organized by the State Key Laboratory of Geohazard Prevention and Geoenvironment Protection of the Chengdu University of Technology (CDUT-SKLGP) from Chengdu, China. It is co-organized by the University of Salerno (Italy), the United Nations University – ITC School for Disaster Geoinformation Management of the University of Twente, the Netherlands, the International Centre for Geohazards (ICG, NGI, Norway) and the Asian Disaster Preparedness Center (ADPC, Bangkok, Thailand). The course was conducted by 10 experts with international reputation, coming from China, Hongkong, Japan, Italy, Norway and the Netherlands, and with 40 PhD student from all over the world.
The LARAM-ASIA international course was conducted in Chengdu, China, with fieldwork in the nearby area where 60000 landslides were generated during the 2008 Wenchuan earthquake. The LARAM-Asia courses will also be organized in 2012 by the State Key Laboratory on Geohazards Prevention, of Chengdu University of Technology (SKLGP) For more information: www.laram.unisa.it.

Photo: Participants of the 2011 LARAM-Asia course in Chengdu, China.

Note:
When using the case studies in a course environment, you are requested to include a reference to this training package.

1.6 INSTALLING THE ILWIS SOFTWARE

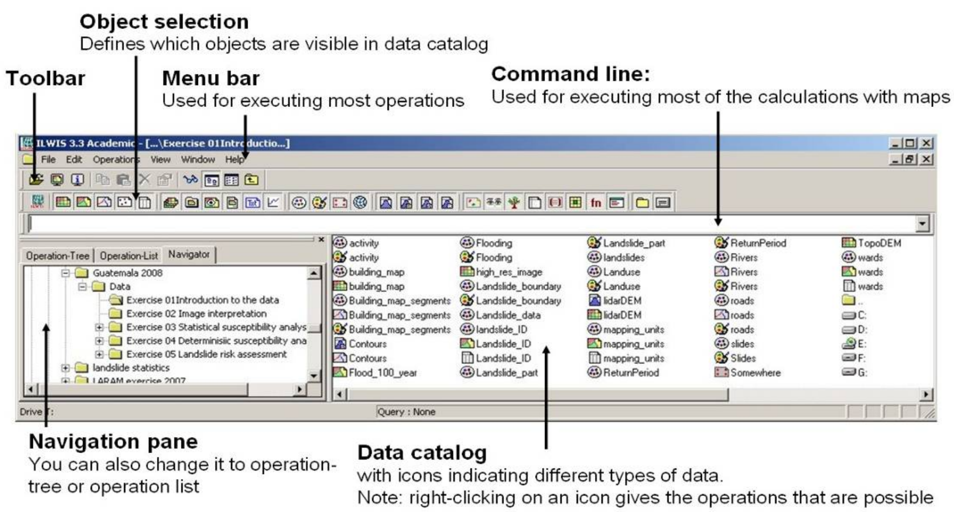
Before you can start with the exercises you will have to download the software. We have decided to use the version 3.4 which is not the most recent version of the ILWIS software, but one which is well proven stable and has all the functionalities required for carrying out the exercises. The latest versions of ILWIS have some major changes in terms of the visualisation and the exercise texts are not adapted to that.

To install the software, please follow these steps:

- Download the file: Ilwis_3.4_Open.zip from the SafeLand website or the ITC ftp site (See above)
- Unzip the file in a directory on C or D drive.
- Run ILWIS34Ssetup.exe to install the software.
- The zip file also contains a directory Users Guide\ This folder contains the complete ILWIS 3.0 User's Guide (in .pdf format). with a file describing what changed in ILWIS 3.1. ILWIS 3.4 has new functionality, but the same file describes how to use the ILWIS 3.0 User's Guide with ILWIS 3.4. Data for these basic tutorials can be downloaded from http://www.itc.nl/ilwis/documentation/version3.asp

In the exercises we are using this font and this colour to indicate the actual software instructions. General information and explanation is written in Black (Times Roman)

- To start ILWIS, double-click mouse the ***ILWIS*** icon on the desktop. After the opening screen you see the ILWIS Main window (see figure below). From this window you can manage your data and start all operations
- Use the ILWIS Navigator (Navigation pane) to go to the sub- folder of the exercise. The Navigator lists all drives and directories (i.e. folders) in a tree structure.



2 CASE STUDY SITES

The test sites selected in this Area are located in 4 different countries: China, Italy, France, and India, and deal with different components related to landslide hazard and risk assessment.

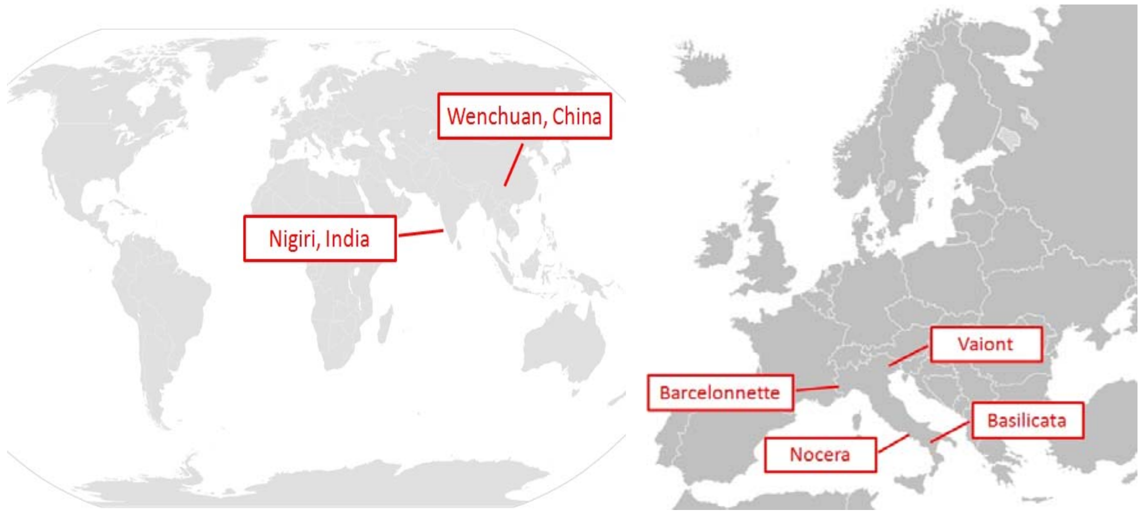


Figure 1 Location of test sites used for the training package

Country	Area	Scale	Topic	Chapter
China	Wenchuan	Regional	Earthquake induced landslide inventories	3
	Beichuan	Local	Change analysis in earthquake area	4
India	Nilgiri	Local	Rainfall threshold analysis	9
	Nilgiri	Local	Quantitative risk assessment along a transportation corridor	12
Italy	Vaiont	Local	Calculation of landslide- and lake volume using multi-temporal DEMs	5
	Basilicata	Medium	Use of weights of evidence modeling for landslide susceptibility mapping	6
	Nocera	Local	Quantitative multi-hazard risk assessment for floods, debrisflows and landslides	13
France	Barcelonnette	Medium	Source area modelling using a heuristic approach	7
	Barcelonnette	Medium	Run-out hazard analysis on a regional scale using the routing-spreading model	8
	Barcelonnette	Medium	Medium scale multi-hazard risk analysis for mass movements	10
	Barcelonnette	Medium	Qualitative multi-hazard risk assessment using Spatial Multi Criteria Evaluation	11

3 INTRODUCTION TO ILWIS AND THE WENCHUAN DATASET OF EARTH-QUAKE INDUCED LANDSLIDES, CHINA

Time: 5 hours
Dataset: **Exercise_Wenchuan.zip** 481 Mb
Objectives:

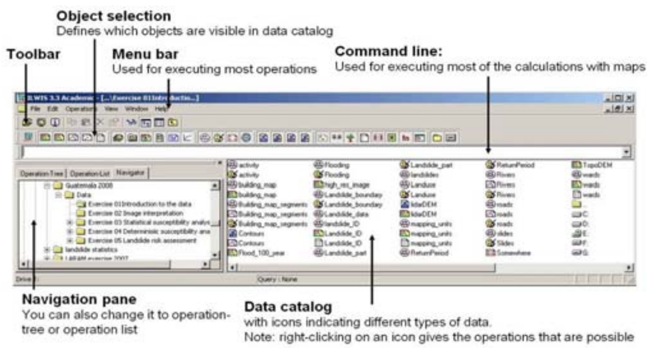
- Learn about the Open Source GIS/Image processing software ILWIS
- Display altitude information
- Analyze landslide inventories for the Wenchuan earthquake and their different characteristic
- Carry out a density analysis
- Analyze the size-frequency distribution

3.1 INTRODUCTION

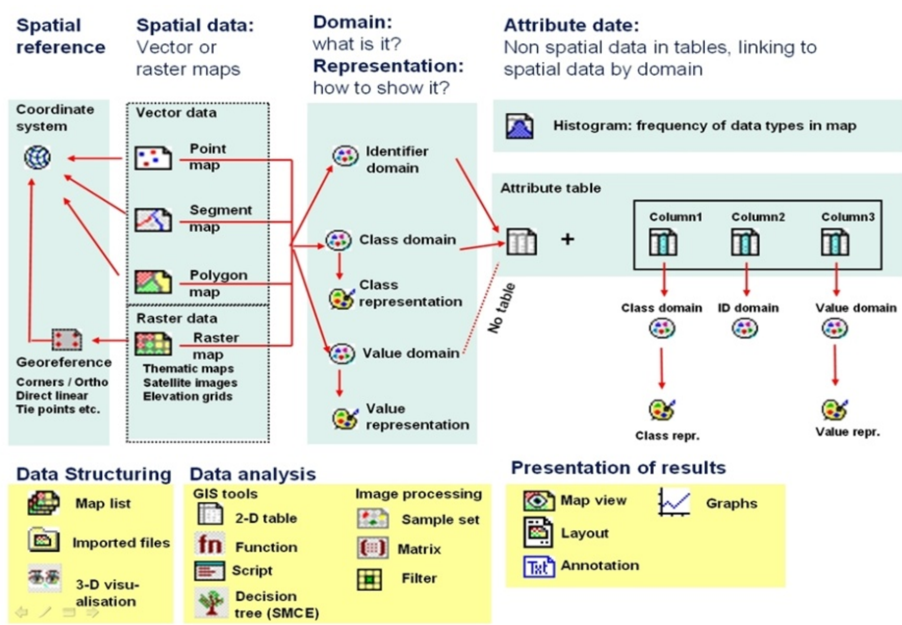
The tutorials made for this week show you the steps required to carry out a quantitative multi-hazard risk assessment using GIS. Given the short time available we will only look at some of the key issues, and in the analysis [part we will also use automated scripts for the analysis. We will use ILWIS. ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with Image Processing capabilities. ILWIS has been developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands, now a Faculty of the University of Twente. We are using the ILWIS version 3.4, which is bit older version of the software but which is stable (whereas the later versions have more functionalioties but also present some more bugs).

ILWIS is an open source software and can be downloaded for free from 52 North: http://52north.org/ As a GIS package, ILWIS allows you to input, manage, analyze and present geo-graphical data. From the data you can generate information on the spatial and temporal patterns and processes on the earth surface.
This exercise will give you an introduction on the basic functions of ILWIS, as we think the best way is to "learn by doing". ILWIS uses vector and raster data, but most of the analysis is done in raster. Below an overview is given of the main features of ILWIS.

- To start ILWIS, double-click mouse the ***ILWIS*** icon on the desktop. After the opening screen you see the ILWIS Main window (see figure below). From this window you can manage your data and start all operations
- Use the ILWIS Navigator (Navigation pane) to go to the sub- folder of the first exercise. The Navigator lists all drives and directories (i.e. folders) in a tree structure.



In the data window you can see the various input data which are either raster maps ( ) , polygons maps ( ), or segment maps ( ). Tables ( ) contain attribute information related to the maps. Domains ( ) are datafiles that explain what is in the maps, and can be compared to legends. Representations ( ) show how domains should displayed. Scripts ( ) are a sequenced list of ILWIS commands and expressions. By creating a script, we have combined many intermediate steps in the analysis so that you can do the exercise without knowing about GIS and ILWIS.



3.2 ANALYZING THE EARTHQUAKE DATA

We will try out the various objects that are in the data catalog, and use that to get an impression on the data for the Wenchuan area.

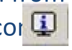
- Double click on the polygon map **China_provinces** . You get information on an area by double clicking. Find Sichuan province.
- Use *Layers/Add Layer* and add the point map **Epicenter**. In the *Display Options* window, select *Single symbol*, click on symbol and make it a red circle.
- Add the segment map **Fault_type_rupture**. Zoom in on the earthquake zone.
- Add also the aftershocks from the map **Aftershocks_CSA**. In the *Display Options* window, select *Attribute*, select the column **Magnitude**, and click on *Symbol*. Select the option *Stretch*, and enter the range 4 to 7.9, and for size from 1 to 40. The aftershocks are now displayed in different size according to their magnitude. Practice a bit with that.
- Open the table **Aftershocks_CSA** and check the contents. How many aftershocks are recorded?
- If we want to know how many aftershocks there have been in different magnitude classes, we can count the number and group them by **Magnitude_class**. You can do that by copying and pasting the data from the column Magnitude into Excel, and do the analysis in Excel. But you can also do that in the table itself. Select *Columns, Aggregation* and select the column **Magnitude**, *Function*: **Count**, *Group By*: **Magnitude_Class**, **Output Table**: *Magnitude_class*, and *Output Column*: **Nr_Aftershocks**. Click OK. And then open the table Magnitude_class to see the results. How many aftershocks large than Magnitude 5 were recorded? Close the tables, but keep the map window open.

We can also evaluate the impact of the earthquake on the region in terms of the number of fatalities. Information is available per county within Sichuan province.

- Add the polygon map **Sichuan_counties** and select Boundaries Only in the *Display Options* window. When you double click on a county you can read the population and the number of fatalities (the information on population is only available for the counties with fatalities).
- You can display this better, by right clicking on the polygon map **Sichuan_counties** in the map window, and in the *Display Options*, deselect *Boundaries Only*, Select *Transparent (50%)* and select *Attributes*. Select the column **Fatalities**, *Representation*, **Pseudo**, and select the Stretch range between **0** and **100**. You can see that apart from fatalities in the counties surrounding the earthquake rupture there are also fatalities in some of the counties located to the SW. Also add the point map **Towns_Sichuan**.
- Open the table **Sichuan_counties** and analyze how many casualties were caused by the earthquake. Which county had the maximum amount of fatalities? You can also calculate the percentage of the population killed per county by writing the following command on the command line in the table window: **Percent:=100*(fatalities/population)** (select default values in the window that defines the output). What is the maximum percentage of casualties? Close the table.

The earthquake happened in a mountainous terrain. We also have a Digital Elevation Model with a pixelsize of 25 meters, derived from the interpolation of digitized contour lines.

- In the map window, deselect the the maps **China_Provinces**, and **Sichuan_counties**. Add the raster map **DEM_Wenchuan**. We can now see the DEM displayed in colours from blue (low) to red (high). When you play with the stretch range you can also see the differences better. Use the mouse to read the values in the map.

- You can also use a better tool for reading map information from many maps and tables at the same time. It is called *PixelInformation*. Select the icon  in the map window. In the *Pixel Information* window, select *File, Add map*, and select the maps **DEM_Wenchuan**, **Sichuan_provinces**, **Aftershocks_CSA**, **Towns_Sichuan**. Select *Options, Always on top*. Move with the cursor over the map, and you can read the information from all maps simultaneously.

The Digital Elevation Model forms the basis for generating many derivative maps (such as slope angle, direction, curvature etc). One very useful one is called a hillshading map (made by filtering the DEM with a shadow filter).

- Close the map window, and open the map **Shadow_map**. We have also extracted the drainage lines from that map. Add the map **Rivers**. Zoom in on the map and evaluate the type of terrain.
- We also have a geological map for the region. Add the polygon map **Geology** with a transparency of 50. Check the various geological units in the area. Ajust the diaply of this map and show the attribute **Lithology** (again with transparency of 50 percent). Which types of lithology are most predominant in the area?

3.3 ANALYZING THE EARTHQUAKE-INDUCED LANDSLIDE DATA

As you know the earthquake in this mountainous area triggered a very large number of landslides. These landslides were mapped by a team under the guidance of Prof. Dai from Beijing, as polygons and by a team from CDUT/ITC as points. Both were mapped no the basis of image interpretation using a large number of pre-and post earthquake images. We will now look at the landslide distribution.

- Add the raster map **Landslides**, using again a transparency of 50. Now you see the landslides displayed on top of the lithology and the hillshading image. Take some time to browse through the image (use also *PixelInformation*) and get an idea of the distribution of landslides in the area, and the relation with the faults, the epicenter, the lithology and the terrain. What are your main conclusions?
- Display several of the attributes of the map **Landslides** (in the Display Options window you can select attribute and select an attribute from the linked attribute table).

The points mapped by the team from CDUT/ITC (PhD Tolga Gorum and Xuanmei Fan) only represent the starting point of the landslides.

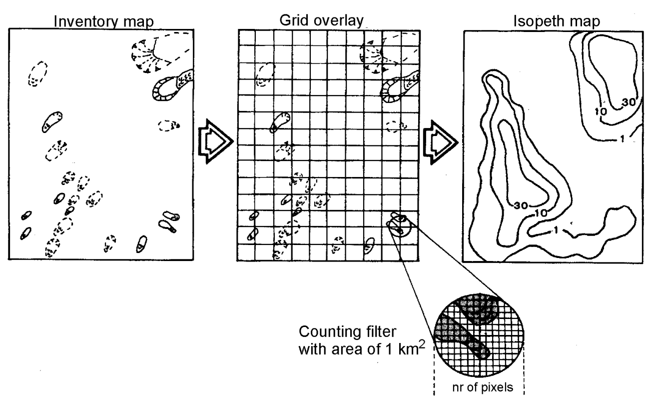
- Add the point map **Landslide_points**, as red dots. Zoom in on some of the landslide areas and compare the information from the landslide polygons with that of the landslide points. What can you conclude on their spatial relation, and on the way they have been mapped? What would cause this?
- There is also a separate map of the landslides that have caused a landslide dam. Deselect the map **Geology**. Open the raster map **dam_polygon** (also with transparency). You can display the attributes of this map, and display the **Landslide part** (including the dammed lakes), the **Landslide_depth** and the **Landslide_type**. For the non-landslide dams unfortunately we don't have information on the landslide types.

Now we would like to concentrate on analyzing the landslide information and get some descriptive statistics, on the number of landslides, the types, the spatial distribution etc. Let us start with the number.

- Open the table **Landslide_points**. How many landslides are mapped in the entire area?
- Open the table **Landslides** (linked to the polygon map). From this table we can evaluate many things.
  - How many landslides have been mapped as polygons? Why is this number different from the landslide points mapped?
  - How many landslides have completely dammed the river?
  - How many landslide have partially dammed the drainage network?
  - How many landslide lakes were there in the study area?
  - What is the relation between landslides and distance to the epicenter?
  - What is the relation between landslides and the distance to the fault rupture?
  - What is the relation between landslides and the fault structures?
  - What is the largest landslide?
- You can pick out one or two of these questions and try to answer these with the data in the table. Or use the Excel sheet with the same data as the table.

3.4 LANDSLIDE ISOPLETHS MAPPING: DENSITY OF LANDSLIDES

A useful way of representing landslides over a large area is as the density of landslides per km^2. This is also called landslide isopleth mapping. The idea is that, after rasterizing the landslides with a certain pixelsize, you apply a circular counting filter that has a total area of 1 km^2, and calculate the density of landslides per km^2. The filter counts for each pixel in a circle around it how many pixels are covered by landslides.



If we use a small pixelsize (e.g. 25 meters) the size of the map is very large (13141 lines and 11413 columns).

- You can check that by opening the georeference **Wenchuan.**

With such a large map the calculation would take too much time now, so we have reduced the pixelsize to 100 meters, and made another georeference (Wenchuan_small) and two raster maps that contain 0 and 1 values for absence or presence of landslides.

- Open the georeference **Wenchuan_small** and check the values for the number of lines and columns and the pixelsize.
- Also display the two maps **Landslide_polygons_small** (where the presence of landslide polygons is shown with 1 values) and **Landslide_points_small** (where the presence of landslide points is indicated with 1 values).

The counting circle can be made in ILWIS as a linear filter. In order to know the size of the counting circle we need to calculate the radius of the circle with the equation Area = πr^2

- Calculate the size of the counting circle if the pixelsize is 100 meters and the area is 1 km.
- Open the filter **Area_density**. You can see that the filter contains 1 values organized as a circle.
- Apply the filter: Select *Operations, Image Processing, Filter*, Select *Raster map*: **Landslide_polygons_small**, select the *Filter name*: **Area_density**, and name the output map: **Area_density_polygons**. Check the results. What do the values mean, given that the counting circle is 1 km^2 and each pixel is 100 by 100 meters?
- Apply the filter also for the map **Landslide_points_small**, and name the output map : **Area_density_points**
- You can also see the difference in densities when you subtract both maps. Write the following command on the command line:
  Area_density_dif:=area_density_polygons – area_density_points
- Is this comparison useful? What can you conclude?

3.5 STEPS FOR ANALYZING SIZE-FREQUENCY DISTRIBUTION

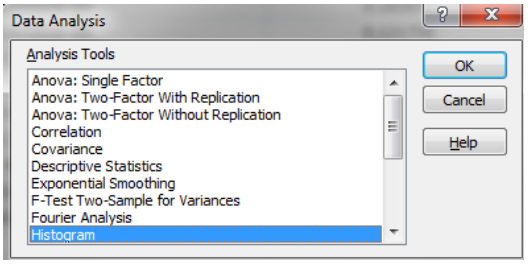
Finally we are going to use the information on the sizes of the landslides and the landslide dams to make a size-frequency distribution. We have converted the area data into an Excel file (**size_freq analysis**).
The equations used in excel for calculating the landslide size probability density (for details, please check Malamud et al., 2004):

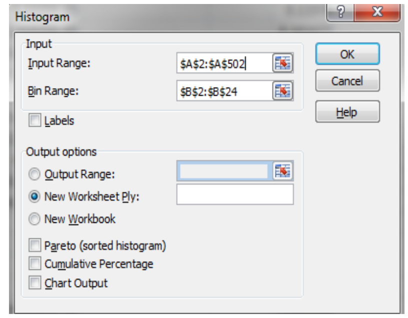
$$p(A_L) = \frac{1}{N_{LT}} \frac{\delta N_L}{\delta A_L} \quad (1)$$

$$\int_0^\infty p(A_L)\,dA_L = 1 \quad (2)$$

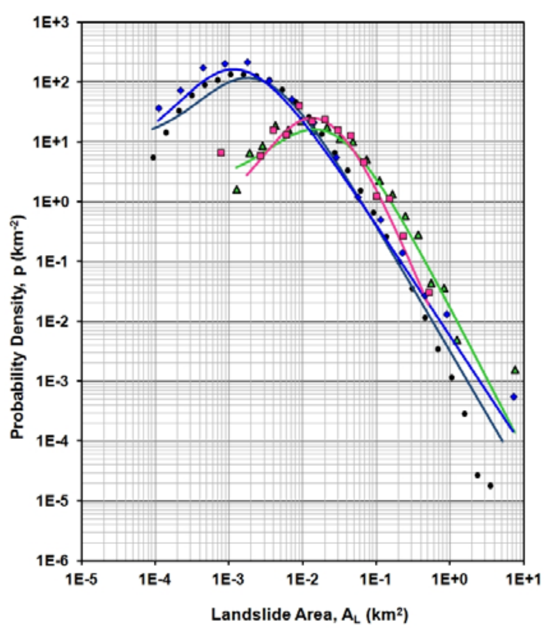
where A_L is landslide area, N_{LT} is the total number of landslides in the inventory, and δN_L is the number of landslides with areas between A_L and $A_L + \delta A_L$.

- Once you have your landslide area or volume data, save it in excel in one column (better to sort the data from smallest to largest, which helps you get the data range immediately); The original data for this exercise is put in A column in excel.
- Decide the bin size (between AL and AL+ δA_L), which usually select as the 1.5 or 2 times of the smallest area or volume in your inventory. We used the 1.5 times of the smallest area in the data, equaling to 1248.88 m2. The largest bin's value is just larger than the largest area or volume in the data.
- Calculate the bin interval, which is actually the δA_L, thus we use bin size values in column B, B (N+1) row – B (N) row;
- Calculate the frequency, the δN_L value, which can be done by the excel "Data"----"Data analysis" tool, then select Histogram, the widow Histogram will pop out, then select the landslide area column as the "Input range" and the bin size column as the "Bin range". Select the "new worksheet Ply" option, you will get a new work sheet with the calculated frequency value (shown in sheet 4).





- Calculate the freq_density, $\frac{\delta N_L}{\delta A_L}$, using the frequency column divide the bin interval column.
- Calculate the probability density, $p(A_L)$, using the freq_density divide the total landslide number (sample number);
- Plot the data;
- Try to analyze the landslide data in the worksheet in the same file.
- If you want to test your calculation is correct or wrong, you can use the test column. If the summed volume is 1 (as shown in Equation.2), it means you have succeeded.
- Finally you will get the results like the figure below. You can also plot different data in one figure, e.g. landslides in blank, barrier lakes in blue, partial damming landslides in pink, and completely damming landslides in green.



4 ANALYZING THE LANDSLIDE EVOLUTION BEFORE AND AFTER A MAJOR EARTHQUAKE: CASE STUDY OF BEICHUAN CITY, SICHUAN PROVINCE, CHINA.

Time: 6 hours
Dataset: **Exercise_Beichuan.zip** Size: 164 MB
Objectives:

- Use multi-temporal images for the mapping and classification of landslides
- Use stereo-image interpretation for landslide mapping
- Evaluate landslide distributions, and relation with causal factors
- Use multi-temporal Digital Elevation Models for landslide volume estimation.

In this exercise we are going to zoom in on the area surrounding the city of Beichuan, which was completely destroyed during the earthquake, by fault rupture, ground shaking, rockfall and landslides, and by debrisflows that happened some months later.

4.1 DISPLAYING IMAGE DATA

We have also a number of high resolution images in the dataset, which are from different dates:

- **Google_2005**: High resolution image downloaded from Google earth and georeferenced
- **Alos_image_2007**: Alos multi-spectral image from 2007
- **Alos_image_2008**: Alos multi-spectral image from 2008
- **Spot_2008**: SPOT image from 2008
- **Google_2011**: High resolution image downloaded from Google earth and georeferenced

With ILWIS it is also possible to compare different images by displaying them in the same map window, and click the display button on and off. We will do this with the images indicated above

- Display the image **Google_2005**. Zoom in on some parts of the map. E.g. on the city center.
- Select *Layers, Add Layers* and select the image **Alos_image_2007**.
- Add the map **Infrastructure_before**.
- Deselect in the left part of the window the boxes to display the last two images. If you click again on and off you can compare the two images.

The first image has a much higher resolution and it is possible to identify the buildings, reads etc. Let us now also look at the post earthquake images.

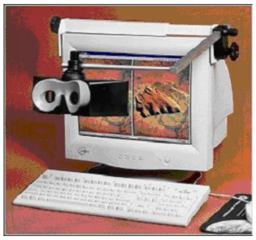
- Select *Layers, Add Layers* and select the image **Alos_image_2008**
- Deselect in the left part of the window the boxes to display the last two images. If you click again on and off you can compare the two images. The Alos image has been used to map the landslide distribution
- Add also the segment map **Landslide_lines**. Check in various parts the quality of the interpretation.
- You can also modify the landslide lines. Select Edit, Edit Layers, and select the segment map **Landslide_lines**.

- Select Insert Mode  to start to digitize new segments. You can also split existing segments to new ones, and after this "snapping" the new segment at the already existing one.
- Use the *Move Point button*  to change the position of the points.
- Use the Select Mode button  to select the object (segments or points).
- Deselect in the left part of the window the boxes to display the last two images.
- Try to map the Tanjianshan landslide yourself (you can see where this is by the red line). The code of the line should be Tanjianshan.
- Click on the Exit Editor button  when you finish.

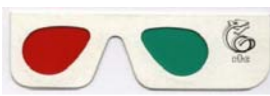
Finally we will look how the landslides look now. There is also a recent high resolution Google image.

- Select *Layers, Add Layers* and select the image **Google_2011** Unfortunately the image is of poor quality because it contains a haze, but it is good enough to see how much has changed since 2008.
- Move the **Landslide_lines** layer to the top of the list.
- Try to identify how landslides have become vegetated again, how some of the main landslides have been removed (e.g. the Tanjianshan landslide) by excavation, how there have been new debris flows (e.g. in the area SW of Beichuan) and how the infrastructure has changed.

4.2 DISPLAYING IMAGES IN 3-D



Stereo viewing is also possible in ILWIS with the images shown above. A stereo pair allows you to view raster maps, scanned photographs or images in stereo, using a stereoscope mounted onto your monitor or red-green or red-blue glasses (anaglyph). A stereo pair can be calculated with the *Stereo pair from DTM* operation with a single raster map as input, for instance a scanned photograph or an image, and a Digital Terrain Model (DTM); in the output stereo pair, you can view the whole area of the input map displayed



A stereo pair can be displayed:

- in a stereoscope window, while using a stereoscope, and
- as an anaglyph in a map window, while using red-green or red-blue glasses. We will use this in this exercises.

For this exercise you are provided with Anaglyph glasses (Red-Blue) which you should return to the teacher once the exercise is completed.

We are going to analyze the situation before and after the earthquake in stereo using two detailed Digital Elevation Models, and two images : a high resolution image from Google from 2005 and the ALOS image of 2008. Unfortunately the latter one is less detailed than the former one.

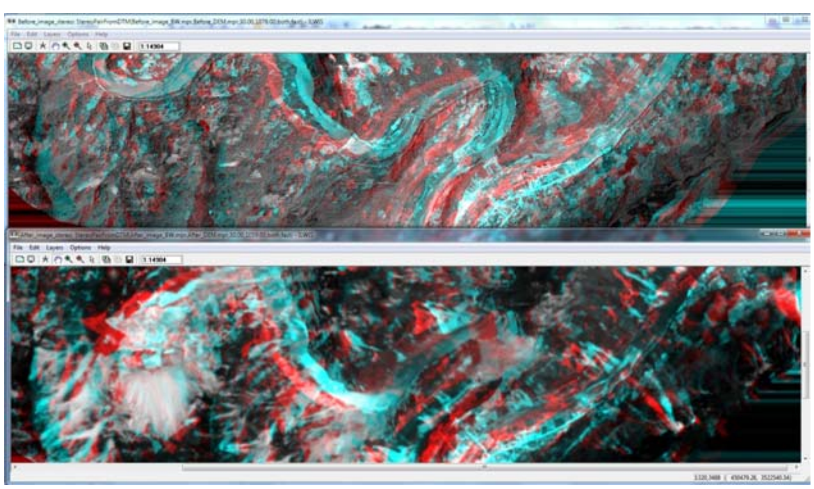
- Open the **Before_image_stereo** icon in the catalog, right click, *Visualization, as anaglyph*. Use the option: *Red-Blue*.
- Overlay the **Landslide_lines** by selecting Layers/Add Layer and check how good it is.

Many of the landslides that have occurred in 2008 were actual re-activations of existing landslides, or there were at least indications of past movements in these locations.

- Check the locations of the Tanjianshan landslide and of the two large mass movements that hit the center of the city of Beichuan. Can you see signs of previous activity?

We can also compare the situations before and after the earthquake with two stereo images that are displayed above each other.

- Open the stereo image **Before_image_Stereo** as anaglyph, and make the window so that it covers the upper section of your screen.
- Open the stereo image **After_image_Stereo** as anaglyph, and make the window so that it covers the lower section of your screen. Make the set-up as shown below. You can copy the scale from one image to the next to make sure they are the same.
- Compare the situations before and after in some more detail.



4.3 DISPLAYING DIGITAL ELEVATION MODELS IN 3-D

We have two Digital Elevation Models that were made from detailed contour lines which were digitzed and interpolation. One of these represents the situation just before the earthquake, and the other one just after. We have resampled the two DEMs to 2 meter resolution.

- Open the raster map **Before_DEM**, and open the raster map **After_DEM**. The maps look rather similar, but the height values can be quite different. Open Pixel Information, and add the two maps. Go over the map and see the elevation before and after.

You can also display the two DEMs as hillshading images. This is done using a filter technique, with a special filter.

- Open the raster map **Before_shadow**, and open the raster map **After_shadow**. (if you want to try to make them yourself: Operations, Image Processing, Filter, input map; Before_DEM, Filter name: shadow, output map: After_shadow_new). The hillshading image of the situation after the earthquake contains a blocky structure which is already available in the original contour lines and cannot be removed now.

The hillshading images can also be displayed in 3-D. We will now make the two hillshading images.

- Select *Operations/Image Processing/Stereopair from DTM*. Select *Raster Map*: **After_shadow**. Select DTM: **After_Dem**, Output stereopair: **After_shadpw_st**. Accept the default settings. Click show. The calculation will take some time. The end result will first display as dual window. Close this and then Open the stereo pair again, selecting Visualization, show as Anaglyph
- Also generate the stereo image for the before situation. Arrange the two images above each other (as you did with the images) and make a comparison.

4.4 CALCULATING VOLUMES OF LANDSLIDE WITH MULTI-TEMPORAL DIGITAL ELEVATION MODELS

The two Digital Elevation Models can also be used to quantify the changes that have taken place. We will calculate the terrain difference and then overlay this with the landslide information in order to calculate the volume of the landslides.

- We start by simply subtracting the altitude values before the earthquake from those of the situation after. This is done using an equation on the command line:
  Dem_difference:= (Before_Dem) – (After_Dem)
- When you display the image using the Pseudo colours you can see that there is a large difference in elevation in some areas (e.g. especially in the Tanjanshan landslide area). There is also a lot of noise in the image, which we would like to remove. Therefore we have made a new representation: **Dem_difference**. Select the Display Options window and change the representation to **Dem_difference**. This displays the values between -10 and 10 as white, negative values (meaning accumulation of materials) in red-orange and positive values (meaning erosion) as shades of green. You can also overlay the raster map **After_shadow** (use transparency of 50) and also overlay the segment map **Landslide_lines**. Evaluate if the major elevation differences coincide with the landslide locations.

Still the result is not as good as we would expect. Although the main landslides show up well with the differences in elevation, many of the smaller landslides do not show differences in elevation, due to the inaccuracies of the pre- and post earthquake contour lines. Therefore we will only concentrate on evaluating the volumes of the 3 main damming landslides, including the Tanjianshan landslide.

- Add the polygon map **Damming_landslide**(boundaries only), and check the results.

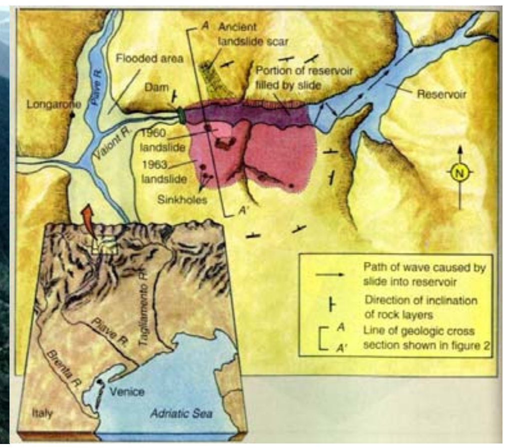
We will overlay the map **Dem_difference** with the map **Damming_landslide**, and will calculate the overall volumes. We will do this using the *Cross* operation.

- Select *Operations, Raster Operations, Cross*, and select **Damming_landslide** as first map, and **Dem_difference** as second map. Call the output table: **Damming_landslide_difference**
- In the resulting cross table, we will now calculate the areas with erosion and accumulation. Negative values relate to accumulation and positive values to erosion. Since the pixelsize is 2 meters, we can calculate volume per pixel by multiplying the height difference with the pixelsize. On the command line write:
  Erosion_volume:= iff(dem_difference>0,4*npix*dem_difference,0)
  Accumulation_volume:= iff(dem_difference<0,4*npix*dem_difference,0)

We will now aggregate all the erosion and accumulation volumes for the various landslide parts. We do this with the aggregation function.

- Close the cross table, and open the Table **Damming_landslide**. Select *Columns, Join*. Select Table: **Damming_Landslide_difference**, select *Column*: **Erosion_volume**, Select: Next, Next, Next, Select the *Aggregation Function*: **Sum**, and *output column*: **Erosion_volume**.
- Close the cross table, and open the Table **Damming_landslide**. Select *Columns, Join*. Select Table: **Damming_Landslide_difference**, select *Column*: **Accumulation_volume**, Select: Next, Next, Next, Select the *Aggregation Function*: **Sum**, and *output column*: **Accumulation_volume**. In the next window select the value range: -1000000 to 0
- Check the results. How can the same areas have both erosion as well as accumulation? You can finally calculate the overall volumes:
  Overall_volume:=(erosion_volume) – (accumulation_volume)
- How do the erosion volumes of the scarps relate to the accumulation volumes of the same landslides?

5 CALCULATION OF LANDSLIDE- AND LAKE VOLUME USING MULTI-TEMPORAL DEMS: VAIONT CASE STUDY, ITALY



Time: 8 hours
Dataset: **Exercise_Vaiont.zip** Size: 6 Mb
Objectives:
Make a photointerpretation of three periods:
- Before construction (1954): recognise the paleolandslide
- After construction (1962): map lake extend
- After the landslide (1964 or 1984): map the new situation

GIS work:
- Calculate the total volume of waterin the reservoir prior to the landslide
- Calculate the volume of water that was removed from the reservoir during the landslide
- Calculate the total volume of eroded materials of the landslide
- Calculate the total volume of accumulated materials of the landslide
- Calculate the total volume of the landslide.

5.1 THE STUDY AREA

The Vaiont reservoir is located in the lower reaches of the river bearing the same name, not far from its confluence with the River Piave. The Vaiont dam, a dome-shaped shell, is one of the highest arch dams in the world, being 265 m high with a 160 m chord, which spans a very deep and narrow gorge. The rock on both sides of the gorge had been skilfully reinforced.

During the night of 9 October 1963, a mass of rock estimated at 270 million m^3, broke loose from the sides of Mount Toc and crashed into the reservoir below in which the water level was about 700 m above sea level (The dam was designed for a water storage level of 722.5 m a.s.l.). The slide moved a 250 m-thick mass of rock some 300 to 400 m horizontally, with a velocity of 20 to 30 m/sec, which rose more than 100 m to 150 m on the opposite bank.

When the disaster occurred, the volume of the reservoir above water level was about 55 million m3. It occurred very suddenly, with extreme violence, and the wave which spilled over the dam crest, overtopped it by 250 m at one point on the right bank and 150 m on the left bank. It is estimated that about 30 million m3 of water poured into the narrow gorge which has a depth of over 240 m and a width of only 150 m at the crest and 20 m at the bottom. The water gushed through this narrow canyon at tremendous speed until it reached the River Piave, where after a right-angle turn it entirely destroyed the small town of Longarone and nearby villages. The collapsed material is now heaped up in what used to be lake and its total height exceeds the dam crest elevation by some 100 m.

5.2 MULTI-TEMPORAL DIGITAL PHOTO-INTERPRETATION

For this exercise you have 4 airphotos available in digital format. A small version of the photos are shown on the next pages.

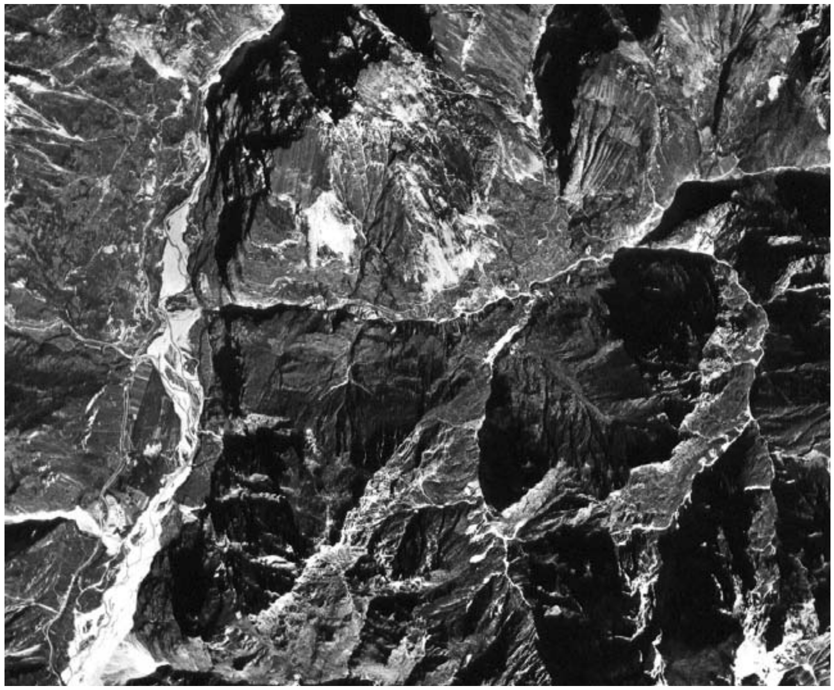


Figure: Airphoto from 1954

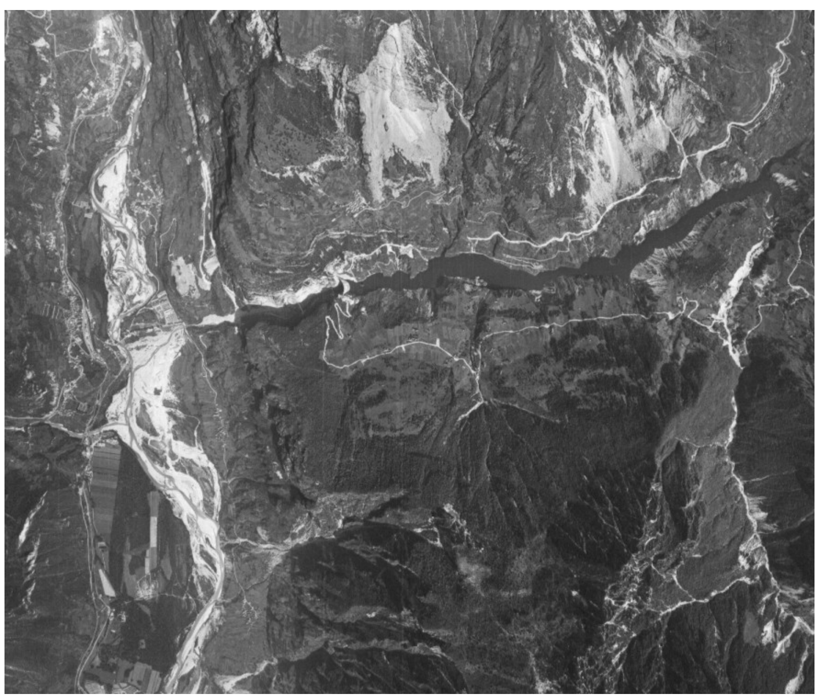


Figure: Airphoto from 1962

Figure: Airphoto from 1962

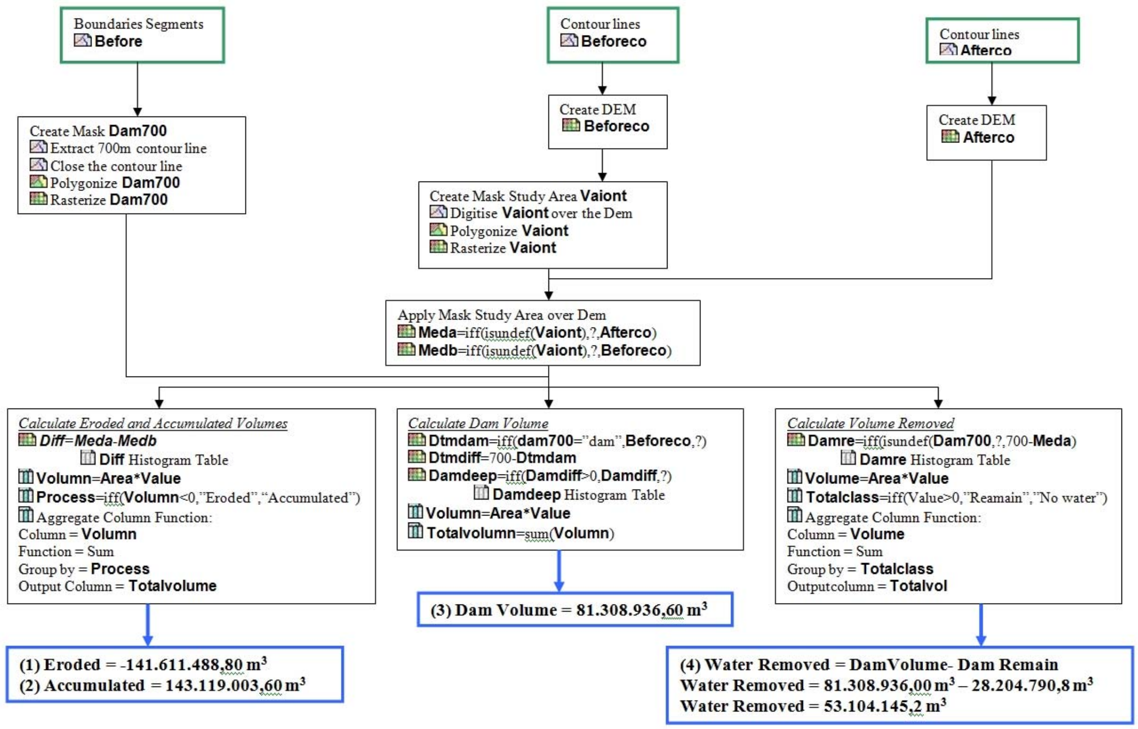
Figure: Airphoto from 1984

- Generate a Digital Elevation Model for the situation before the event using the contour map **Beforec** using the Georeference **Vaiont,** name the DEM **BeforeDEM**.
- Generate a Digital Elevation Model for the situation before the event using the contour map **Afterco** using the Georeference **Vaiont,** name the DEM **AfterDEM**..
- Georeference the aerial photograph **Photo_1954** using the operation: File, Create Georeference, Direct Linear, with the map Photo_1954 as background map and **BeforeDEM** as the DEM. Name the Georeference **Photo_1954**.
- Select at least 10 ground control points of points that you can recognize in the photo and also in the digital maps available. The sigma should be around 1.
- Do the same for the other photos: **Photo_1962**, **Photo_1964** and **Photo_1984**.
- Resample all the photos after finishing with the georeferencing to the georeference Vaoint. Name the result files: **Ph_1954, Ph_1962, Ph_1964** and **Ph_1984**.
- Create stereopairs from these photos, using the DEM **BeforeDEM** for the **Ph_1954** and **Ph_1962**, and the DEM **AfterDEM** for the other two.
- Analyse the four stereopairs in stereo using anaglyph glasses. Also compare the photos and record the changes
- Describe the major changes that can be observed between each period. Indicate wheter you can identify the old landslide prior to the event.

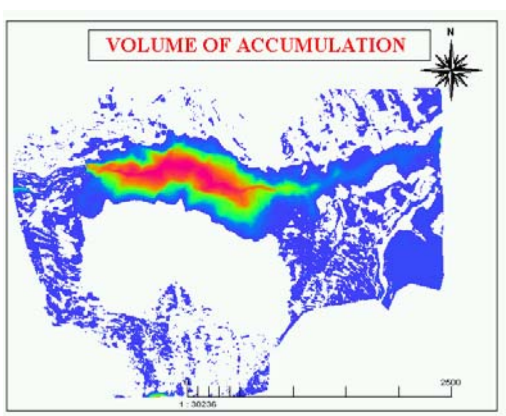
5.3 ANALYZING THE VOLUMES OF THE LANDSLIDE, THE LANDSLIDE DAM, AND THE LAKE.

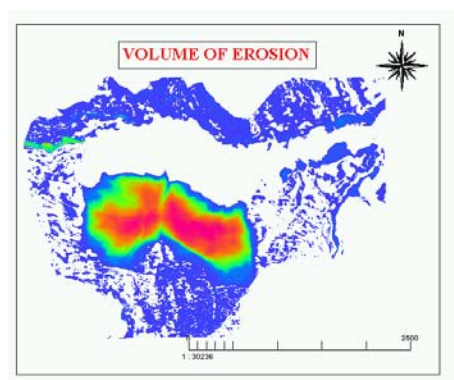
The flowchart in the figure 1 explain the procedure followed for the volume calculation and can be explained in the following steps:

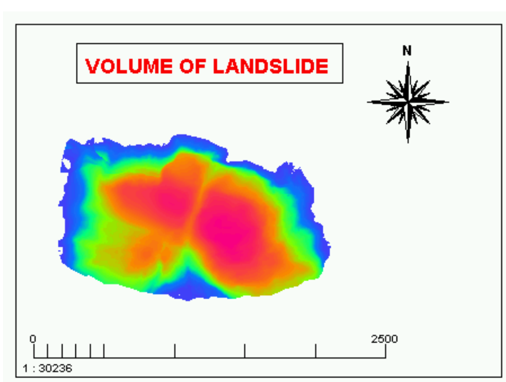
- Create the digital elevation models (DEM) at 1 meters resolution from the segments contour maps after and before.
- Create the mask for the study area digitised over one of DEM.
- Apply the study area mask for both DEM.
- Create the mask for the Dam at 700.00-meter level
- Calculate eroded and accumulated Volume.
- Calculate differences between both DEM:
- In the Histogram of the differences map, calculate the volume.
- Classify the process in “Eroded” and “Accumulated”.
- Adding the volume of both processes by the Aggregate Column Function, group by process type. The result will give the total eroded and accumulate volume values.
- Calculate Dam volume.
- Extract the DEM before the event for the Dam area.
- Subtract at 700 m Dam level, the DEM for the Dam.
- Extract the positive values of the Dam deep.
- In the histogram of the Dam deep map calculate volume per value.
- Adding all volume value will give the total volume of the Dam.
- Calculate the Volume Removed:
- For the Dam area subtract at 700.00 meter level the DEM after the event.
- In the of subtracted map histogram, calculate volume multiplying area per map value.
- Classify the areas in water “remain” and “no water” areas.
- Apply the Aggregate Column Function adding the volume values group by “remain” and “no water” classes. The remained total volume value will give the water which no went out of the Dam.
- Obtain the removed water volume subtracting the total Dam Volume minus remain Dam volume.

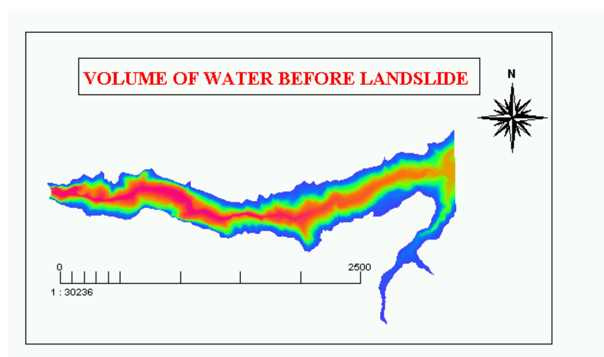


Flowchart of the method followed for the volume calculation.









6 USE OF WEIGHTS OF EVIDENCE MODELING FOR LANDSLIDE SUSCEPTIBILITY MAPPING: ALVARO AREA, BASILICATA, ITALY

Time: 10 hours
Dataset: **Exercise_Basilicata.zip** Size: 532 MB
Objectives:
In this project component you will learn how to apply a method for bivariate statistical analysis, called weights of evidence modeling (WOE) to the dataset from the Alvaro area in Basilicata, Italy for regional landslide susceptibility assessment.
You will learn how to:

- Perform the analysis one a single map using a combination of map crossing and table calculations
- Perform the analysis automatically using a script, so that you can do the analysis faster on more input maps
- Combine the input maps into a prediction map, which you will classify using the success rate method.

This case study deals with methods for data-driven modeling in a GIS. Several approaches to analyze multiple maps are introduced by means of a number of basic exercises that follow closely the chapter "Tools for map analysis: multiple maps" from the book Geographic Information Systems for Geoscientists, by Bonham-Carter (1994). The various methods, in the book illustrated with a hypothetical landfill site selection problem and mineral potential mapping, will be treated in our case study with a real world data set from the Alvaro Area, Basilicata, Italy. In this project you will learn how to calculate prior probability, conditional probability and the positive and negative weights used in the weights of evidence modeling. Weights are combined for a number of factor maps, and a total weight map will be generated. This map is classified using the "success rate". The predicting power is checked by analyzing the "prediction rate". Also emphasis is given to the automatic calculation of weights using ILWIS script files.

6.1 GETTING STARTED

- Copy the data for the exercise to a user directory on your hard disk first.

In this exercise we will assign weights by statistical procedures. The weights of different classes are determined by calculating densities. The method is therefore "data-driven".
We will use another problem for the statistical analysis: the prediction of areas that are susceptible for the occurrence of landslides. In the statistical modeling of landslides we use the rule "the present and past are the key to the future". This means we can look at the conditions under which landslides have occurred in the past, and use the critical combinations for predicting the possible occurrence of landslides where the same conditions prevail, but which are still landslide free.
A flowchart of the method is presented in figure 1.
The input data (table 1) consists of a map containing information on the features you would like to predict (in this case landslides), which is called an evidence map. And the data set contains a number of factor maps that may control the occurrence of the feature you would like to predict.

- Open the orthophoto map: **San Lorenzo**
- Display the map **Slides** on top of this.
- Move through the map and press the left mouse button for information on the various units. As you can see the area outside of the landslides reveals a ? (undefined) when you press the left mouse button. These areas are called undefined. This means that no information is stored for the non-landslide areas. The landslides themselves all have a unique code.
- Move your mouse pointer to one of the landslides and double click on it. Now the information from the table connected to the map **Slides** is displayed.

The map **Slide** has a so-called identifier domain. This means that each unit (land-slide) from this map has a unique code.

Table 1: Available data for project

File	Description	Filetype	Domain	Attribute table
GIS Data				
`Slides`	Evidence map: landslide map	Polygon	ID: Slides	Slides
`SlideT`	Landslide map made by another person for a larger area	Polygon	ID: SlideT	SlideT

Contours	Contour lines	Segments	Value	No
Geom	Geomorphological map	Polygon	Class: geom.	No
Slopecl	Slope classes	Raster	Class: slopecl	No
Geological map	Geological map, scanned	Raster	Picture	No
Geollines	Digitized lithology and geological structure	Segment	Class: geollines	No
Material	Surface materials	Polygon	Class: material	No
Drainage	Drainage network	Segments	Class: drainage	No
Roads	Road network	Segments	Class: roads	No
Buildings	Buildings and settlements	Polygons	Class: buildings	No
Outline	Boundary of study area	Segments	Class: outline	No
Outline large area	Boundary of larger study area	Segments	Class: outline	No
Orthophoto maps with contour lines (1:10000)				
Aliano	Map sheet Aliano (upper right)	Raster	Image	No
San Lorenzo	Map sheet San Lorenzo (Lower right)	Raster	Image	No
La Serre	Map sheet La Serre(Lower left)	Raster	Image	No
Gallicchio	Map sheet Gallicchio (Upper Left)	Raster	Image	No

Apart from the GIS data there are also a number of multi-temporal aerial photographs of the study area, that can be used in the project to carry out a landslide activity assessment.

When you move the mouse pointer to one of the landslides, you will see that the attribute table contains information for Type, Subtype, Activity, Depth, and Part.

- Each time you double click on a part of the map, the information from the table for that unit will be displayed. Try this out for several different units. Close the Edit Attribute window.
- Open the pixel information window and drag-and-drop the map Slides into it. Now if you move with the mouse pointer the information is shown without the need to double-click.
- To see what the table looks like, go to the main ILWIS window and open the table Slide by double-clicking it. Have a look at the different columns. If you double-click the name of a column you get information on the column type.
- Close the table window.

The columns Type, Subtype, Activity, Depth, Vegetation, Scarp are class domain columns. These names are defined in the domain files. The various domain items of these columns are shown in table 2.

Table.2: List of domain items for mass movement characteristics

	Type	Subtype	Activity	Depth	Part
1	Fall	Rotational	Stable	Shallow	Scarp
2	Topple	Translational	Dormant	Deep	Transport zone
3	Slide	Rot & transl.	Active	Unknown	Body
4	Flowslide	Complex	Reactivated		Unknown
5	Flow	Debrisflow	Unknown		
6	Badland	Earthflow			
7	Unknown	Unknown			

- Open the domain **Activity** by double-clicking it. As you can see each class has a code, which corresponds to the values in the left column of table 2. Each class domain also contains a representation, in which the colors for each class are defined.
- Open the representation **Activity** and have a look at the content. After that close the representation and the domain.

You can also display the map **Slide** with an attribute from its table.

- Make the landslide map **Slide** active. Press the right mouse button while in the map, and select: *1.map Slide*. In the following Display Options dialog box click on Attribute and select the column **Activity**. Press OK. Now the map is redisplayed, with the colors from the representation **Activity**. If you click on a landslide you will see the activity information displayed.
- Also try this with some other columns (**Type, Subtype, Activity, Depth**, and **Scarp**).

Apart the from landslide map **Slide** which is made by one person for a smaller study area, another landslide map is also available, called **SlideT**, for a larger area including the small area.

- Display the map **SlideT** and the map **Slides** together. Check the contents of the two.
- What can you say about the differences? Try to quantify the differences, in terms of number of landslides, and area for different landslide types.

Along side the landslide map you also have a number of factor maps that might be controlling the locations of landslides: **Slopecl** (slope classes), **Geom** (geomorphological units), **Contours** (from which we can generate a DEM and derivative maps such as slope classes, or slope direction), **Material** (surface materials), **Drainage** (from which distance to drainage can be derived), **Roads** (distance to roads) etc.. Unfortunately we do not have a good land use map for the area, but this could be generated using the available imagery

- Open the map **Slopecl** and consult the information from the map and the accompanying table.
- Add the other available maps and check their contents.

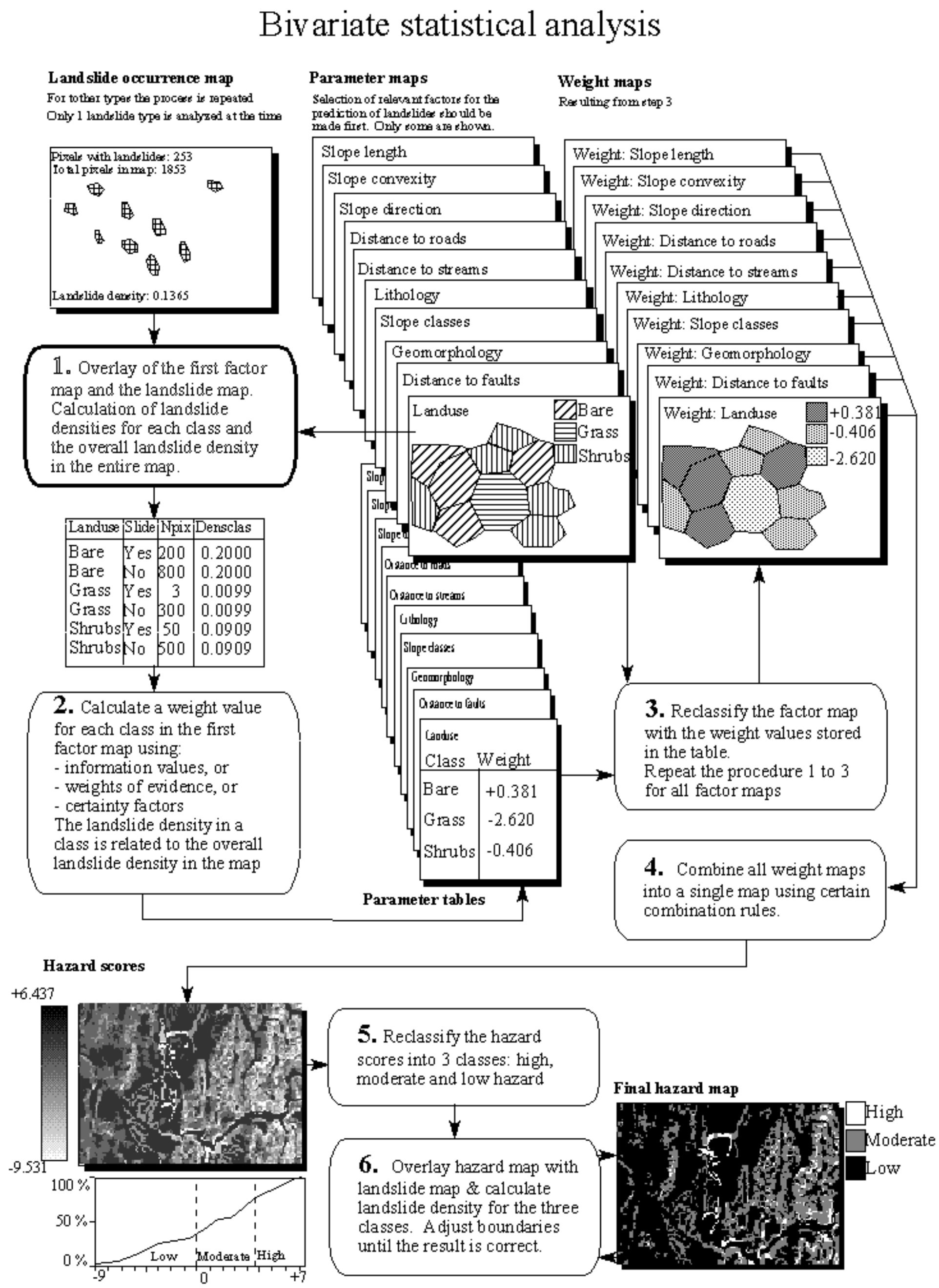


Figure 1: Simplified flowchart for bi-variate statistical analysis.

So far you have only been looking at the content of the maps. As you can see nearly all maps are still in vector format, whereas the analysis will be carried out using raster maps. Table 3 shows the data conversion operations that are still required. Now we will only do some of these. The other operations are done later on in the project.

	Input Map	What to do?	Output map
Rasterizing input maps			
1	`Geom`	Rasterize using 10 meter pixel size, and georeference Alvaro	Geom
2	`Material`	Rasterize using georeference Alvaro	Materials
3	`Slides`	Rasterize using georeference Alvaro	Slides
4	`Outline`	Generate a polygon map and rasterize using georeference Alvaro	Outline
5	`Outline_large_area`	Generate a polygon map and rasterize using georeference Alvaro	Outline_large_area

We first need to convert the vector files into raster maps, as the analysis is done in raster.

- Rasterize the map: **Geom** and use the georeference **Alvaro** with 10 meter pixelsize..
- Use this georeference to rasterize the maps: **Material** and **Slides**
- Generate a polygon map from the segment map **Outline** and rasterize using georeference Alvaro
- Do the same for the segment map **Outline_large_area**.

6.2 CALCULATING LANDSLIDE AREA AND NUMBERS

Previously you displayed the activities of the landslides in the study area. However, you did not actually make a new map showing these activities. This is what you will do now, by renumbering the map Slides with the attribute **Activity**.

- Calculate the histogram of the map Slides, and join the column Area in the attribute table **Slides**.
- In the table Slides, use aggregate function SUM with the columns **Area** (don't group) to calculate total area of all landslides. Do the same for the column **NrPol**.
- Then calculate the total area of all landslides using aggregate SUM on Area, and the total number of landslide using aggregate sum on **NrPol**.
- Now you can calculate how many landslides are present in the area, with the different types and activity classes (active, dormant, stable), and what is their area. Fill in the results in the table below.

		Total Area	% All landslide area	Total number	% All landslides	Average landslide area
Slide	Active					
	Dormant					
	Stable					
Flow	Active					
	Dormant					
	Stable					
Deep landslides						
Shallow landslides						

6.3 CALCULATING PRIOR PROBABILITY

Consider that you would only have the landslide map of the area, without any additional data. How to answer the question: what is the chance of having a landslide in a particular part of the area (in a randomly selected pixel)?

If there is no additional information, i.e. if you do not know whether you are in a geological unit with many landslides, or on a steep slope, we speak of the prior probability. The prior probability that a certain pixel in the map will have a landslide is simply the density of landslides in the entire area. In other words, the number of pixels with landslides, divided by the total number of pixels in the map.

$$P_{Prior} = P\{S\} = \frac{Area(Slide)}{Area(Total)}$$

In a formula that is:

where: Pprior = P{S} Conditional probability of having a landslide S; Area (Slide)= Area with landslides in the map; Area (Total) = Total area in the map

- Calculate the prior probability for all landslides in the study area
- Calculate the prior probability of the active landslides in the study area
- Calculate the prior probability for all different landslide types.
- Write the results in the table below.

	All landslides	Active	Fall	Topple	Slide	Flow
Size of Study Area						
Area of landslides						
Prior probability						

6.4 CALCULATING CONDITIONAL PROBABILITY

If we have more information available than just the landslide map, we can see what will be the probability that we may have a landslide, given that we are in a certain Geomorphological unit, for example. If we are in the Slope class "steep slopes" the probability that there may be a landslide is obviously much larger, then when we are on “Flat areas”. This is what we call conditional probability. Considering the relationship between a binary variable map (B) and a landslide map: (S). The probability given a certain condition can be expressed as:

$$P\{S|B\} = \frac{P\{S \cap B\}}{P\{B\}} = \frac{Npix\{S \cap B\}}{Npix\{B\}}$$

P{S|B} the conditional probability of having a landslide while you are in unit B.

In other words, the conditional probability of having landslides, given that you are in a certain unit, is the density of landslides within that unit, calculated as the number of pixels with landslides in the unit, divided by the total number of pixels in the unit.

- Create an attribute map **Activity** from the column **Activity** in the table **Slides**.
- Convert this into a bit map showing only the Active, Reactivated and Dormant landslides: **Active**. You can do that by making a map calculation formula, involving also the map Outline. The output map should have 1 values (landslides), 0 (rest of the study area) and ? (undefined, outside of the study area).
- Cross the slope class map **Slopecl** with the map **Active** and calculate the conditional probability for each of the classes.
- Evaluate which classes have a higher value for the conditional probability than the prior probability calculated in the previous exercise. Write the results in the table below.

	Area of the class	Area with landslides in the class	Conditional probability
Flat			
Gentle			
Moderately steep			
Steep			
Very steep			

6.5 CALCULATING POSITIVE AND NEGATIVE WEIGHTS

In this case study the weights of evidence method (Bonham-Carter, 1994) was selected for the indirect landslide susceptibility assessment. In this method positive and negative weights (Wi+ and Wi-) are assigned to each pixel of the factor maps (e.g. each lithological unit within a lithology map). See handouts for more explanation.
For each factor there are four possible combinations, of which the frequency, expressed as number of pixels, can be calculated with a GIS (see table 4).

		B_i : Potential landslide conditioning factor	
		(Present)	(Absent)
S: Landslides	Present	$Npix_1$	$Npix_2$
	Absent	$Npix_3$	$Npix_4$

Table 4: Four possible combinations of a potential landslide conditioning factor and a landslide inventory map. Npix = number of pixels.

In order to be able to calculate these four combinations in the case when we are working with a multi-class map, instead of with a bitmap, we need to calculate the following columns in the joint-frequency table (cross table):

nmap = total number of pixels in the map
nslide = number of pixels with landslides in the map
nclass = number of pixels in the class
nslclass = number of pixels with landslides in the class

The values needed for the weight formulas are:

npix1 = nslclass
npix2 = nslide-nslclass
npix3 = nclass-nslclass
npix4 = nmap-nslide-nclass+nslclass

The weights are calculated as:

W+ =ln((npix1/(npix1+npix2))/(npix3/npix3+npix4))
=ln((npix1*(npix3+npix4)/((npix1+npix2)*npix3)

W- =ln((npix2/(npix1+npix2))/(npix4/npix3+npix4))
=ln((npix2*(npix3+npix4)/((npix1+npix2)*npix4)

Let us now calculate with ILWIS the weights for the map `Slopecl`. We will only use the landslides that are classified as *active*, since some of the old landslides have occurred in other climatic conditions. If they would also be used, the results would be difficult to interpret.

-
- Cross the map **Slopecl** with the map **Active** indicating only the active slides. Save the cross table as **Slopeclact**
- Carry out the same calculation steps as you did in the manual example in the handouts, but now as a series of Table Calculation statements and aggregation function within the crosstable **Slopeclact** .
- Calculate the weights for the classes of the map **Slopecl**. Make sure to write down all command that you perform (the actual commands on the command line)
- Repeat the procedure but now do the calculation not in the crosstable, but in the attribute table linked to the domain Slopecl. You will have to use aggregation and join functions for that. Write down the command line statements.
- Evaluate the results.

6.6 CALCULATING FINAL WEIGHTS AND CONTRAST FACTORS

Since all of the maps are multi-class maps, containing several factors (classes), the presence of one factor (e.g. one specific slope class) implies the absence of the other factors of the same map (e.g. slope class). Therefore in order to obtain the total weight of each factor, the positive weight of the factor itself should be added to the negative weight of the other factors in the same map. This is done by first adding up all negative weights of the classes of one map, in a column using an aggregation function (SUM). The final weight is then calculated as:

Wmap = Wplus + Wmintotal – Wmin

In which Wmintotal = the total of all negative weights in a multiclass map

- Calculate the final weights and store them in the attribute table **slopecl.**

To quantify the spatial association between a map class and the occurrence of landslides, the contrast factor as mentioned in Bonham-Carter (1994) is defined:

$$C_w = W^+ - W^-$$

The contrast factor is 0, when the landslide pattern and map class pattern overlap only by the expected amount due to chance, positive when there is a positive association between the two patterns and negative when there is a negative association between the two patterns.

- Calculate the contrast factors and store them in the attribute table **slopecl**.

6.7 USE OF SCRIPTS

Because the same calculation has to be performed for the other maps, it would be useful to automate the procedure. This can be done with a SCRIPT, i.e. a text file in which the exact procedure followed in the program and the formulas are stored.

You can find all operations that you have done with ILWIS in the so-called ILWIS.LOG file. The commands from this file can be copied to a script file in ILWIS.

- Repeat the procedure, writing down the exact command line procedures
- Create the script. Use %1 in the script in stead of the name of the map, so you can use it as variables. Name the script: **WOE** (if it is too difficult we already made one)
- Run the script for the map **slopecl** by typing : **run WOE slopecl**
- If the script "hangs" check where the error occurs and correct it in the file, then run the script again, until everything is correct.

The script for weight of evidence modeling is shown below.

When the script runs without problems, it can also be used for the other maps.

- Also include the cross operation in the initial part of the script.
- Use the script to calculate the weights for the other factor maps: material and geom.
- Indicate which classes are most important for the prediction of landslides. Order the ten most important classes in a table.
- Include this table and the script within your report for this exercise.

```
rem ILWIS Script for Weights of Evidence
//The parameter %1 refers to the name of the factor map. It should be less than 7 characters long.
// Make sure that each map has a domain with the same name
//FIRST WE WILL DELETE EXISTING RESULT FILES
// the crosstable s%1.tbt
//The attribute table %1.tbt
// and we make a new attribute table
del s%1.*
del w%1.*
del %1.tbt
crtbl %1 %1
//NOW WE CROSS THE FACTOR MAP WITH THE ACTIVITY MAP
// The landslide map should be called ACTIVE and should have either 0 or 1 values. 1 values mean
landslides.
// The cross table is called s%1
s%1=TableCross(%1.mpr,active.mpr,IgnoreUndefs)
calc s%1.tbt
//Now we calculate one column in the cross table to indicate only the pixels with landslides.
Tabcalc s%1 npixact=iff(active=1,NPix,0)
//NOW WE USE AGGREGATION FUNCTION, WITH OR WITHOUT A KEY TO CALCULATE:
//NCLASS = number of pixels in the class. We sum the values from columns Npix and group them by %1
//nslclass = number of pixels with landslides in the class.We sum the values from columns Npixact and
group them by %1
//nmap = number of pixels with landslides in the map. We sum the values from columns Npix and don't
group them
//nslide = number of pixels with landslide in the map. We sum the values from columns Npixact and don't
group them
//THE RESULTS ARE NOT STORED IN THE CROSS TABLE S%1 BUT IN THE ATTRIBUTE TABLE %1
Tabcalc s%1 %1.nclass = ColumnJoinSum(s%1.tbt,Npix,%1,1)
Tabcalc s%1 %1.nslclass = ColumnJoinSum(s%1.tbt,Npixact,%1,1)
Tabcalc s%1 %1.nmap = ColumnJoinSum(s%1.tbt,Npix,,1)
Tabcalc s%1 %1.nslide = ColumnJoinSum(s%1.tbt,Npixact,,1)
//NOW WE CALCULATE THE FOUR VALUES NPIX1 - NPIX4 AS INDICATED IN THE EXERCISE BOOK. THIS IS
DONE IN THE ATTRIBUTE TABLE
// We correct for the situation when Npix1 - Npix3 might be 0 pixels, and change it into 1 pixel
Tabcalc %1 npix1 =IFF((nslclass>0),nslclass,1)
Tabcalc %1 npix2 = IFF((nslide-nslclass)=0,1,nslide-nslclass)
Tabcalc %1 npix3 = IFF((nclass-nslclass)=0,1,nclass-nslclass)
Tabcalc %1 npix4 = nmap-nslide-nclass+nslclass
//NOW WE CALCULATE THE WEIGHTS IN THE ATTRIBUTE TABLE
Tabcalc %1 wplus {dom=value.dom; vr=-10:10:0.00001} =
LN((npix1/(npix1+npix2))/(npix3/(npix3+npix4)))
Tabcalc %1 wminus {dom=value.dom; vr=-10:10:0.000001} =
LN((npix2/(npix1+npix2))/(npix4/(npix3+npix4)))
//NOW WE CALCULATE THE CONTRAST FACTOR
Tabcalc %1 Cw = wplus-wminus
//NOW WE CALCULATE THE FINAL WEIGHT
//The final weight is the sum of the positive weight and the negative weights of the other classes
Tabcalc %1 WminSum=aggsum(wminus)
Tabcalc %1 Wmap=wplus+Wminsum-Wminus
//NOW WE MAKE AN ATTRIBUTE MAP OF THE FINAL WEIGHTS
w%1.mpr = MapAttribute(%1,%1.Wmap)
calc w%1.mpr
```

6.8 COMBINING WEIGHTS OF DIFFERENT FACTOR MAPS

In real world situations, the occurrence of landslides will seldom be associated with only one, or a few spatial variable. Landslide occurrence for example is not only dependent on slope steepness but also on the geological unit on which it occurs, and many other factors. Ultimately we want make a prediction based on a number of maps that are likely to be useful to predict the occurrence of landslides.
We can use the weights calculated for the individual factor map for an assessment which maps are important for the prediction in combination with our expert knowledge. We have to make sure that the output tables with the weights can be linked to the factor maps. That is why the weight calculation is done in the attribute tables, and not in the cross tables.
The weights of the individual factor maps can be summated to obtain a total weight map. The higher the values in this map, the higher the susceptibility for landslides.

- Generate attribute maps of the attribute **Wmap** for the various factor maps slopecl, **geom**, and **material**.
- Add a last line to your script Weight that does this attribute map creation automatically.
- Sum up all the weight maps. Calculate a histogram of the final weight map
- How would you classify this map in the classes high, moderate and low ?

6.9 CALCULATE SUCCESS RATE & PREDICTION RATE

The "predictive power" of the resulting weight maps can be tested by analyzing their success rate and prediction rate. The success rate is calculated by ordering the pixels of a susceptibility map in a number of classes, from high to low values, based on the frequency information from the histogram. After that an overlay is made with the landslide inventory map, and the joint frequency is calculated. The success rate indicates how much percentage of all landslides occurs in the pixels with the highest values in the different combination maps. For example, 50 percent of all landslides are predicted by 10 percent of the pixels with the highest value in the map.

Success rates are useful for two purposes:

- Classification of the weight map into classes with a predefined percentage of all landslides. For example: you can then define high susceptibility as the class where 80% of all landslides are occurring, moderate as the class where 19% of all landslides happen, and low as the class where 1% of all landslides can happen.
- The success rate is also used to check how well the final weight map can "predict" the landslide pattern with which it was made. It is of course essential that most of the landslides occur in the locations with the highest weights.

- Create a script for the calculation of the success rate, using the information from the lecture handouts.

- Calculate the success rate using the landslide inventory map slides. Make a graph from it and decide on the best boundary values for dividing the map in high, moderate and low susceptibility.
- Use these boundaries to classify the weight map again.

```
//script for success rate calculation
// one parameter %1 = weight map resulting from the statistical analysis

del active%1.* -force

// Cross Final with Map: active
Active%1.tbt := TableCross(%1,active,IgnoreUndefs)

//In the cross table, calculate
tabcalc Active%1 npixact:=iff(active=1,npix,0)
tabcalc Active%1 Npcumactive = ColumnCumulative(npixact)
tabcalc Active%1 totalslide = ColumnAggregateSum(npixact,,1)
tabcalc Active%1 totalarea = ColumnAggregateSum(npix,,1)
tabcalc Active%1 percentage:=100*(Npcumactive / totalslide)
tabcalc Active%1 Percentlandslide:=100-percentage
tabcalc Active%1 Npixcumul:= cum(NPix)
tabcalc Active%1 reverse = totalarea -npixcumul
tabcalc Active%1 percentmap = 100*(reverse/totalarea)
// after this display a graph with Percentlandslide az y-axis and Percentmap as x-axis
```

Apart from the success rate, the prediction rate really gives a good estimation of the predictive power of the map. The prediction rate is carried out with two landslide inventory maps of two different periods. The oldest one is used to generate the model and the weight map is than combined with the recent landslide inventory map in order to test how well it predicts. In order to be able to do this you will need to have a landslide map from another period, that you can generate from the available airphotos. You will do this later as a possibility in the project. For the time being we will use another landslide map SlideT to check how well the model made with only three input maps (geom., slopecl and Materials) behaves in a larger area.

- Adapt the script for the calculation of the success rate, so you can use it for the calculation of predication rate.
- Calculate the prediction rate using the landslide inventory map SlideT.
- Explain how well the model predicts the landslides in the larger area.

6.10 ANALYSIS WITH MORE INPUT MAPS

In the previous exercises you have learned the various steps for executing a weights of evidence analysis. However, the final map was not made by careful consideration of the input data.

There were several simplifications that we assumed, such as:

- we didn't look at different landslide types. You can imagine that flows will have a different combination of causal factors than Slide or Fall..

- we didn't take only the scarp areas of the landslides, but also the accumulation areas. You can imagine that the accumulations areas have quite different factors than the erosional parts, e.g. the slope angle is much smaller. The landslide susceptibility analysis is specifically for initiation modeling, and therefore only those conditions should be taken into account where landslides originated.
- We also didn't look at many different factor maps. Of course there are more factors that may cause landslides than slope, geomorphology and materials, that we have used sofar.

For the project you have to perform weights of evidence modelling on the same data set more accurately, using more factor maps. An overview of the available , and possible factor maps are shown in table 5.

One set of data is related to a DEM. We will also need to have a Digital Elevation Model , from which a more detailed slope gradient map can be made as well as a slope aspect map, and other derivative maps.

- Generate a DEM from the contourlines using the georeference Alvaro. Name it **DEM**.
- Use the ILWIS procedures to generate a Slope gradient map (call it Slopes) and a Slope Aspect map (call it **Aspect**). Consult the ILWIS help for more information on how to do this.
- Classify the Slope map in classes of 5 degrees, and the slope gradient map in classes of 45 degrees (name the result maps: **SlopeCl**, and **AspectCl**)
- Alternative 1: you can also use many classes and then in the table calculate the Contrast Factors for different classes, so that you can decide which class division is the best.
- Alternative 2: you can also evaluate the use of other derivative maps from DEMs, like flow accumulation, slope length etc.

One set of data is consists of maps that show buffer zone around features that might be beneficial for the occurrence of landslides, e.g. faults, drainage (undercutting), Roads (road cuts, or drainage from the road), or buildings (slope cuts).

- Rasterize the segment map, and generate a distance map from it.
- Determine how wide the buffer should be. This depends on the cause of landsliding and may be different for each map.
- Alternative : you can also use many classes and then in the table calculate the Contrast Factors for different classes, so that you can decide which class division is the best.

You don't have to make all of the factor maps now, especially not the ones that require more digitizing and interpretation. One of these can be made as an additional task in the project.

- Evaluate all available input data
- Select the input landslide set you want to work with.
- Use the script Weight to calculate the final weights for all factor maps. You can also use another script that contains the names of the factor maps and that runs the script weight.

- Sum up all the weight maps. Calculate a histogram of the final weight map. Create a final classified weight map

Table 5: Overview of possible factor maps in the landslide susceptibility assessment

	Input Map	What to do?	Output map
Rasterizing input maps			
1	Geom	Rasterize using 10 meter pixel size, and georeference Alvaro	Geom
2	Materials	Rasterize using georeference Alvaro	Materials
3	Slides	Rasterize using georeference Alvaro	Slides
DEM generation and creation of DEM derivatives			
4	Contour	Contour interpolation, using Georeference Alvaro	DEM
5	DEM	Create DX, and DY maps using filter operation	DX and DY maps Raster
6	DX and DY	Calculate a slope map	Slope
7	DX and DY	Calculate a slope map	Aspect
8	Slope	Classify the slope map in relevant classes	SlopeClass
9	Aspect	Classify the aspect map in relevant classes	AspectClass
10	Flow accumulation	Classify into relevant classes	FlowAcc
11	Wetness index	Classify into relevant classes	Wetness
12	Slope convexity	Classify into relevant classes	Convex
Factor maps made from buffering			
13	Geological_map	Screen Digitize faults from geological map	Fault
14	Faults	Make buffer around faults. Determine how wide the buffer should be.	Faultzone
15	Drainage	Make buffer around drainage. You can do this also depending on stream order. Determine how wide the buffer should be	DrainageZone
16	Roads	Make buffer around roads. You can do this also depending on slope gradient. Determine how wide the buffer should be	RoadZone
17	Building	Make buffer around buildings. Determine how wide the buffer should be	BuildingZone
Additional factor maps made through digitizing			
18	Lithological map	Screen Digitize from geological map	Lithology
19	Landuse_97	Screen Digitize from ortho-images from 1997	Landuse97
20	Landuse_76	Screen Digitize from colour photographs from 1997	Landuse76
21	May be you know another one….?		

Apart from these general aspect, we expect that you investigate another aspect in your group, and report on that as well. We expect that you deal with at least one of the topics given below.

Analyze the difference in weights for different landslide types.

Do the statistical analysis based on different landslide types in the map Slides. You can look at different landslide types. You can imagine that flows will have a different combination of causal factors than Slide or Fall. You can also take only the scarp areas of the landslides, and leave out the accumulation areas. You can imagine that the accumulations areas have quite different factors than the erosional parts, e.g. the slope angle is much smaller. The landslide susceptibility analysis is specifically for initiation modeling, and therefore only those conditions should be taken into account where landslides originated. Quantify the difference.

Analyze the effect of a different landslide map.

We have two different landslide maps: SlidesS and SlideT. These are made by two different persons, and they haven't mapped the same landslides always. The person mapping SlideT also mapped a larger area. Now the research question is: what is the difference in weights if we use SlideS or SlideT ? Can we use the weights made from SlideS and apply them to the entire area?

Use multi-temporal landslide data and calculate a prediction rate

Generate a multi-temporal landslide map using image interpretation. Start by combining the landslide from the two landslide maps: Slides and SLideT, into a single map, with an attribute table. Then generate digital stereo images of the airphotos from different periods (discuss among your group and with other groups who does what?). Overlay the landslide map on it, and make a column in the attribute table that indicates if the landslide was Absent, Fresh, Partly vegetated, or completely vegetated.

From susceptibility to hazard…..

In order to go from landslide susceptibility to landslide hazard, we need two other aspects: the temporal probability and the magnitude- frequency distribution. Make a frequency – magnitude map of the landslides of different types in the study area Use the multi-temporal landslide map in the statistical analysis: use the landslides present in one period to generate the susceptibility map, and check the results with landslides that have happened in a later period. Further improvement: make a multi-temporal land use map, and see if landuse has played a major role in the landslide occurrence.

Include more geological factors

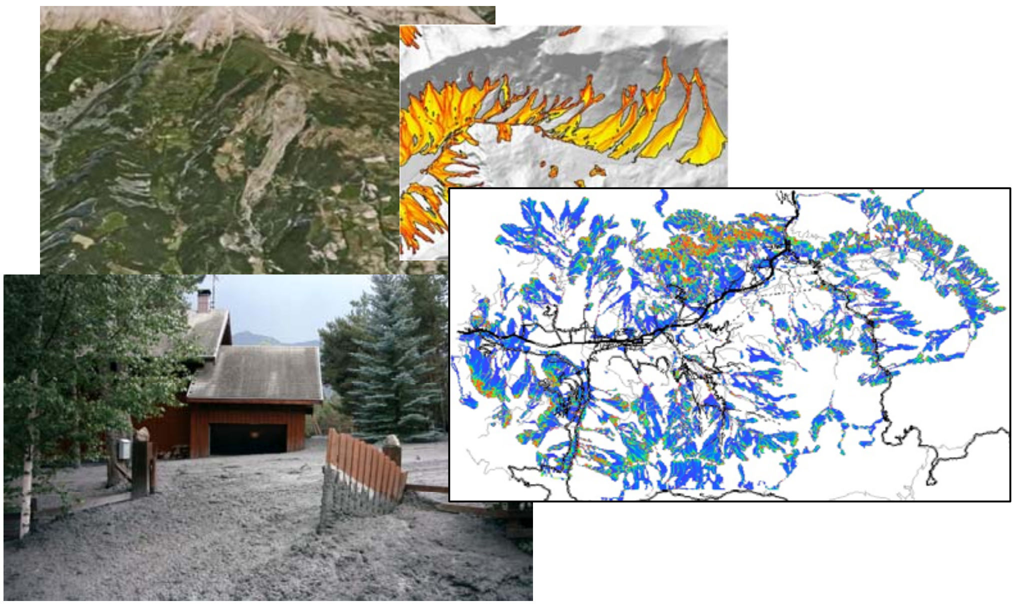
From the geological map, generate a lithological map using screen digitizing, and generate a map with faults and anticlinal axes. Use a relevant buffer zone for these

You could also consider to make a land use map based on the interpretation of the ortho-photos from 1997.

Reference

Bonham-Carter, G.F. (1994). Geographic Information Systems for Geoscientists. Modelling with GIS. Computer Methods in the Geosciences, 13: pp 267- 302. Pergamon.

7 SOURCE AREA MODELLING USING A HEURISTIC APPROACH: CASE STUDY FROM BARCELONNETTE, FRANCE



Expected time: 4 hours
Data: **Exercise_Barcelonnette_source.zip** Size: 2.3 Gb
Objectives: After this exercise you will be able to:

- understand the basic functions and objects of the ILWIS software
- get an overview of the dataset for Barcelonette
- analyze the data that are relevant for a specific hazard type
- use basic GIS functions to analyze the source areas for mass movements.

7.1 INTRODUCTION

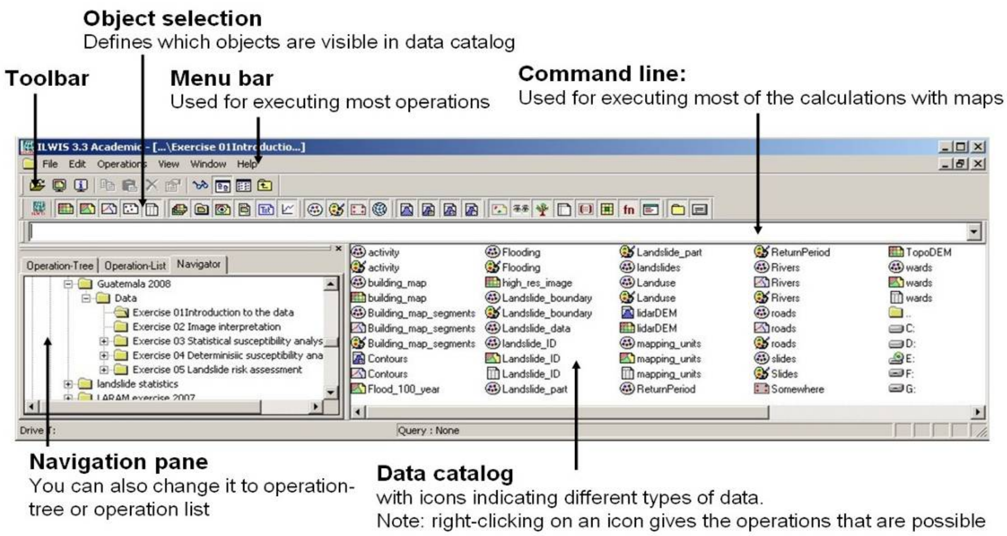
This exercise gives an overview of the main aspects of ILWIS and a scheme of the structure of the software and the icons used. It also aims to explore the available input data for this case study, and show you some aspects of Barcelonette and the associated hazards and risks

Each of the exercises will use its own dataset. So make sure that you copy the data for each exercise to your hard disk in a separate subdirectory. Do not use data for a previous exercise, as we will changes parts of it to make them suitable for the next exercise.

This exercise shows you the basic ILWIS interface, with the ILWIS Objects and Domains.

☞ To start ILWIS, double-click mouse the ***ILWIS*** icon on the desktop. After the opening screen you see the ILWIS Main window (see figure below). From this window you can manage your data and start all operations

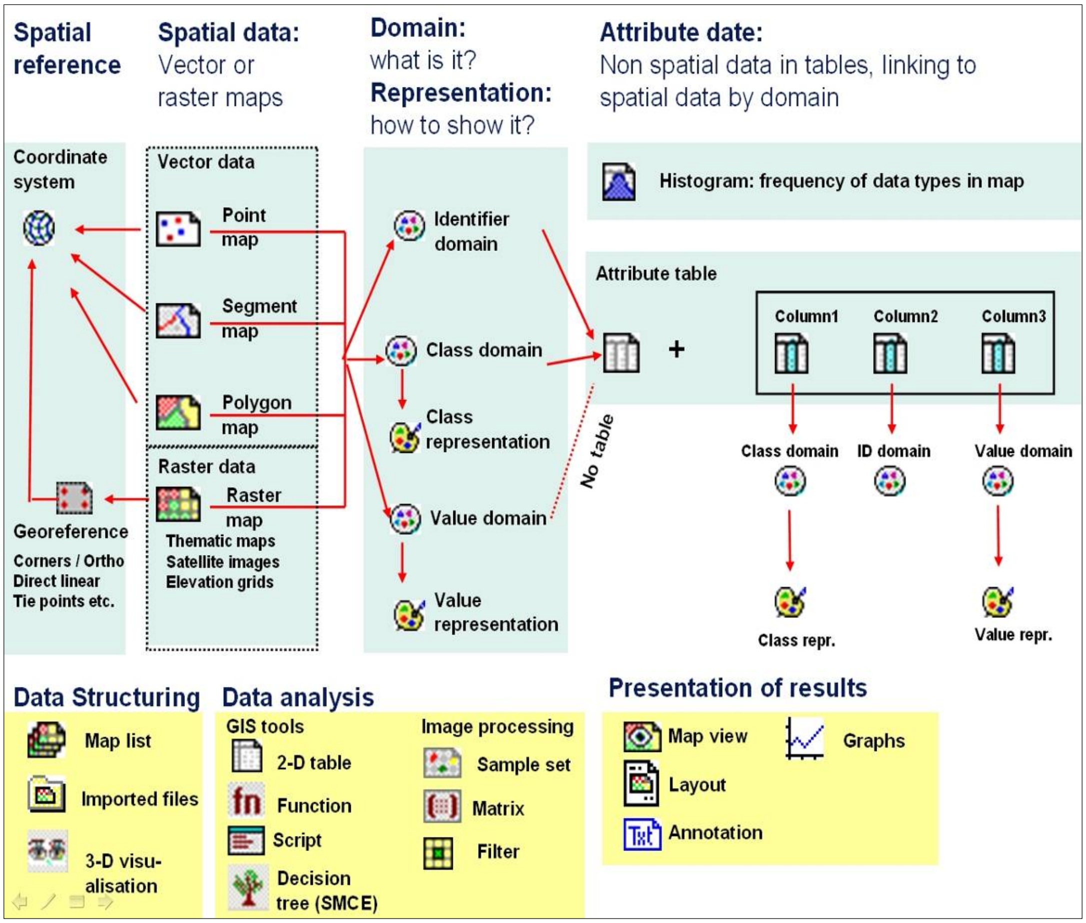
- Use the ILWIS Navigator (Navigation pane) to go to the sub- folder of the first exercise. The Navigator lists all drives and directories (i.e. folders) in a tree structure.



Before we are going to display vector and raster maps and investigate the different types of domains, it may be useful to explain that ILWIS uses different types of objects.

- ***Data objects.*** Raster maps, polygon maps, segment maps, point maps, tables and columns are called data objects. They contain the actual data.
- ***Service objects***. Service objects are used by data objects; they contain accessories that data objects need besides the data itself. Domains, representations, coordinate systems and georeferences are called service objects.
- ***Container objects.*** Container objects are collections of data objects and/or annotation: map lists, object collections, map views, layouts and annotation text.
- ***Special objects.*** Special objects are histograms, sample sets, two-dimensional tables, matrices, filters, user-defined functions and scripts.

A vector map needs a coordinate system, a domain and a representation. These service objects are also needed for raster maps, together with another type of service object: a georeference. In this chapter we will focus our view on data and service objects.



The icons in the **Data Catalog** of the exercise refer to some of the various objects that are possible in ILWIS. When you double-click an object in the Catalog, it will be displayed.

Objects for spatial reference:

They define the coordinate system, projection parameters, and size and pixel size of the raster maps in the dataset. Normally all spatial data has the same coordinate system, and all raster data shares the same georeference.

* Right-click in the Data Catalog the GeoReference Barcelonette and after this select: Properties.
* In the Properties of Georeference window you see the corner coordinates of the GeoReference window and the Coordinate System Lambert_new.
* Select the Tab Used By. Now you see a list of all the raster maps which make use of this GeoReference. It means that they all have the same coordinate system, cover the same geographic area and also have the same pixel size.
* Double-click in the Data Catalog the Coordinate system Barcelonette and look at the projection parameters. All the maps in the dataset use this coordinate system.

Objects for Spatial data:
This can be either vector data (point, lines called segments, and polygons, which are made from points and lines) or raster data (which can be images, thematic data derived from rasterizing vector maps, or interpolated values like Digital Elevation Models).

- Double-click in the Data Catalog the Raster map Barcelonette_image. Click OK in the Display Options window. This is a high resolution image of the study area, which is displayed in a map window. You can zoom in and see the details on the landuse, landslides, buildings and infrastructure.
- In the map window select Layers, Add Layers. A window opens from which you can select to display vector data. If you select another raster map you will get a message that this cannot be displayed on top of another raster map. Select the polygon map Landuse_2000. Accept default values in display options. Now the landuse map is shown on top of the image. You can also display them transparent. Click in the legend of the map window on Landuse_2000. The display options window opens again. Now select the box Transparency, and select 90 percent. Click OK. Now you can see both the image as well as the landuse map. Select the arrow from the tool bar and click on the map: you can read the landuse for every location.
- Add the polygon map Building_map. In the display options select Attribute. Select the attribute Building_use, and the representation Building_use. Display the map, and zoom in on some buildings. When you double click on them a window will open with all attribute information, that is stored in an attribute table.
- Add also segment maps Streams , Road&powerline, and Contours.

Display also various other maps that are in the data catalog. For instance also check out the DEM related maps (see also the overview table

Domain and representation
This is the central component of ILWIS. A domain defines the contents of the data. Five domain types are possible:

- Identifier domain: ID domain in which each unit has a separate code,
- Class domain: all units with the same class have the same name, for instance. lithological units.
- Value domain: each unit contains a value, e.g. a Digital elevation Model. It has a default value range between -9999999.9 and 9999999.9,
- Image domain: Value range from 0 – 256 for 8 bit satellite images,
- Color Domain: used for pictures such as photographs and scanned pictures, for instance maps.

The concept of **domains** is different from other GIS software and might seem a bit confusing in the beginning. However you will see that it is a very powerful component of ILWIS.

Domains are linked to representations, which define how the spatial data is displayed. You can create your own representations (only for Value and Class domains) or you can use standard representations.

- Double-click in the Data Catalog the Class Domain Landuse. You see that there are classes with the names of the landuse types. In ILWIS you don't have to remember which number relates to which class, because the class name is always shown.
- Mouse-click the icon Representation belonging to this Class Domain. You see that there are colors assigned to the different river classes. The colors can be edited easily. Examples of other class domains are Building_use, Materials and communes.
- Select the Help for more detailed background information on the Class Domain.
- Open in the Data Catalog now the Identifier Domain Avalanche_ID_field. You see that each individual snow avalanche has an unique code. Select Help for more detailed background information on the ID Domain.
- Note that the Value Domain is not displayed in the Data Catalog. This is because it is a standard domain. It has a default value range between 9999999.9 and - 9999999.9. In the exercise it is used for the for the Segment map Contour. In this map the contours have values between 900 and 1315 meter above mean sea level.

Tables and histograms:

Attribute data is stored in the form of tables, which are linked to the spatial data through the domains. Only ID and Class domains can have a table. Statistical information on the spatial data is stored in Histograms, containing the frequency information (area, number of pixels, number of points, lines etc). Tables have columns which also have either a Class, ID or value domain (some exceptions are possible)

Select: *Help > Help on this window* for more detailed background information on the Table

- Double Mouse-click in the Data Catalog the Table Building_map. Now the table opens, with is linked to the building map. You see that there are several columns with different types of data.
- Double Mouse-click the column name (top of column); the Column Properties window opens with the Domain used.

Dependency in ILWIS

ILWIS is an object-oriented GIS and image processing software. This means that the various objects mentioned above are related to each other.

> The concept of **dependency** is one of the key features of ILWIS. ILWIS stores for each file the history of how it was made, and the user can easily update a map or table if one of the source data was changed.

There are some things you need to know about using ILWIS data files that will prevent problems when you are using them in the course. Due to the dependency and the object oriented structure of the ILWIS data, individual files are linked to others, and several files are needed to display a map, table or other object.

Do NOT use Windows Explorer to copy / delete or rename individual files. Use the options in ILWIS itself (under Edit) to copy or delete files. You can copy files in ILWIS by going in the main window to Edit and select Copy.

ILWIS has a very extensive Help. Consult this whenever you have specific questions on the functionality of the software.

7.2 EXPLORING THE INPUT DATA

In the data catalog you see the icons of the available input data for this introduction to the case study. The following input data gives an overview of the thematic data and how they are derived.

Name	**Type**	**Meaning**
Image data		
Barcelonette_image	Raster image	This represents a high resolution colour image derived from Google Earth. It has been orthorectified, and resampled to 1.5 meter pixel size.
Stereo_image	Raster image	This is a stereo-image made from the high resolution image and the DEM that you can see using anaglyph glasses.
Elevation data		
Contours	Segment map	This file contains contour lines with 5 meter contour interval.
DEM	Raster map	Digital Terrain Model showing the elevation of the terrain made by interpolating contour lines into a raster
Slope_angles	Raster map	Slope angles in degrees made from the DEM
Slope_classes	Raster map	Slope classes used in the hazard analysis, with classes (< 5 flat, 6-20 sloping, 21-40 steep, >40 very steep)
Slope_direction	Raster map	Slope direction classes made from the DEM (8 classes in compass directions)
Hillshading	Raster map	Hillshading map made from the DEM and stretched
Openness	Raster map	Special hillshading map which better shows terrain differences
Flow_accumulation	Raster map	Flow accumulation map with number of upstream pixels made from the DEM
Plan_curvature	Raster map	Plan curvature map made from the DEM
Elements at risk		
Communes	Polygon map	A polygon map representing the administrative units within the area. In the accompanying table information is given on the number of people.
Building_map	Polygon map	Building footprint map of the city with attribute information on building types and uses.
Cadaster	Segment map	Cadastral map of the Barcelonette area
Road&Powerline	Segment map	A segment map of the streets, roads, paths, skilifts and powerlines with attribute information.
Landuse_2000	Polygon map	Landuse map of the year 2000. Also landuse maps of earlier periods are available
Bridge	Point map	Location of bridges
Pylons	Point map	Location of pylons of powerline and skilifts
Ski_resorts	Polygon map	Map of ski resorts
Flood data		
Flood_100y – Flood 500y	Raster map	Flood extend map for a 100, 150, 250 and 500 year return period, obtained through modeling with HEC-RAs hydrological software
Streams	Segment map	A segment map of the drainage network, digitized from topographic maps

Name	**Type**	**Meaning**
Snow avalanche data		
Avalanche_ID_field	Polygon map	Polygon map with historic snow avalanches mapped in the field
Avalanche_ID_photo	Polygon map	Polygon map with snow avalanches interpreted from aerial photographs
Avalanche_runout	Raster map	Snow avalanche runout map made with Flow-R
Debris flow data		
Debris_flow_high	Raster image	Debris flow runout map generated with FLOW-R programme.
DF-hazard_torrents	Polygon map	Debris flow runout map made with PCRASTER/MASSMOV for three catchments
Landslide data		
Landslide_2007	Polygon map	Landslide map with attribute information on types etc.
Landslide_hazard_expert	Polygon map	Landslide susceptibility map made by experts, with attribute information.
Susc_sh_translational	Raster map	Susceptibility map for shallow translational landslides for the eastern part of the area, made through statistical analysis
ZERMOS_hazard_map	Raster map	Official hazard map made by government organization for the western part of the area.
Sh_trans_runout	Raster map	Runout map for shallow translational landslides, made with FLOW-R programme
Materials	Polygon map	Surface material map
Lithologies	Polygon map	Lithologies in the eastern part of the area
Rockfall data		
Rockfall	Polygon map	Rockfall accumulation areas

7.3 ANALYZING THE HIGH RESOLUTION IMAGE DATA IN STEREO

We start by looking at the high resolution image in stereo. We have made the image from the high resolution image and the DEM. You can view it using anaglyph glasses.

Form a group of 3 persons and select one of the following hazard types: **landslides, debrisflows, rockfall, snow avalanches** or **flooding**.
The aim is to evaluate where the type of hazard that you have selected is occurring and what are the main controlling factors. We will use this then later in the selection of the source areas for the particular landslides

- Right_click on the stereo pair **Stereo_image** and select: visualization, Open as Anaglyph. Select red-blue. The anaglyph image opens (it is a large file so it might take some time). You can zoom in and see the terrain using the anaglyph glasses.
- Click the Pixel Information button on the main screen 

- Add the relevant maps for your particular hazard type. See table above. You can also add the relevant maps for the elements at risk.
- Select Options >Always on top. Now browse through the image and evaluate the image in stereo while comparing the different input maps
- You can also display the maps on top of the **Barcelonette_image**.
- Make a characterization of the factors that control the occurrence of the particular hazard process.
- Do you see any signs of other locations of hazardous processes that are not in the inventory maps?

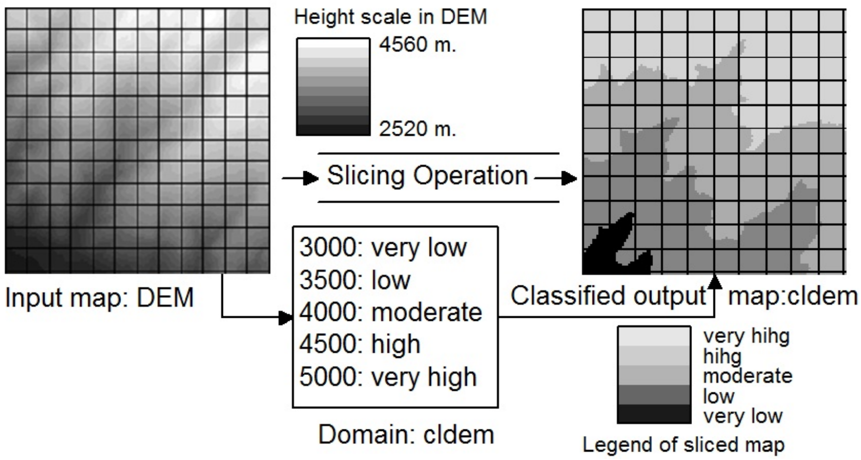
7.4 GENERATING SOURCE AREAS FOR HAZARD PROCESS

The aim of this exercise is to make 3 maps that indicate the possible source areas for either rockfall, snow avalanches, landslides or debrisflows., based on the criteria that you have defined before. In reality we should do this through susceptibility modeling, either making use of heuristic, statistical or process modeling. In this approach we will adopt a simple method for heuristic analysis.

The objective of this exercise is to work in groups and define the potential source areas for either: **landslides, debrisflows, rockfall, snow avalanches** or **flooding**.
The source map should contain only two values: **1** for the source areas and **0** for the rest of the area.
For the hazard type that you have selected, make three of such maps that indicate areas with high, moderate and low susceptibility.

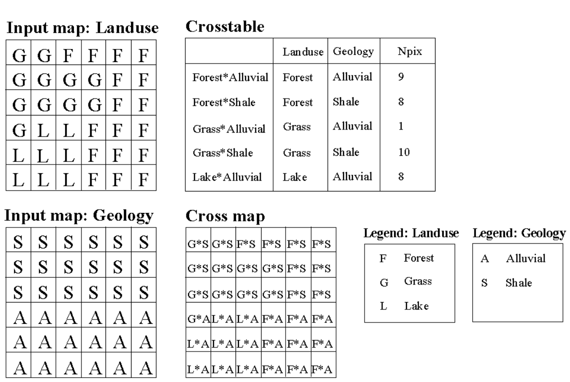
There are many ways in which you can combine several factor maps to get the combinations that are considered best as source areas. We give the possibility to use two options:

Method	Advantage	Disadvantage
Option 1: Cross table / joint frequency tables	Allows you to evaluate all possible combinations between factor maps and make the best expert judgement	Works only with class maps. Value maps need to be converted into class maps first.
Option 2: Two-dimensional tables	Allows to select the combination of two class maps in a user-friendly manner	Works only with class maps. Value maps need to be converted into class maps first. You need to combine more than 2 maps in a stepwise approach.



Value maps, such as Flow_accumulation, plan_curvature, slope_angles etc. need to be converted to class maps first. Take for example a Digital Elevation Model (DEM). This is a value map which contains a wide range of values.In such a case it is much easier to use a so-called classify table. A classify table contains only the input boundary values and the output class names. In ILWIS the concept of classify tables is applied in the Slicing operation. The classify table in ILWIS is called a Class/Group domain; it contains the input boundary values and output class names. Ranges of values of the input map are grouped together into one or more output classes. The output map resulting from the Slicing operation is a map with the domain type Class/group. A domain group should be created beforehand or during the operation using the Map Slicing dialog box; it lists the upper boundaries of the groups and the group names.

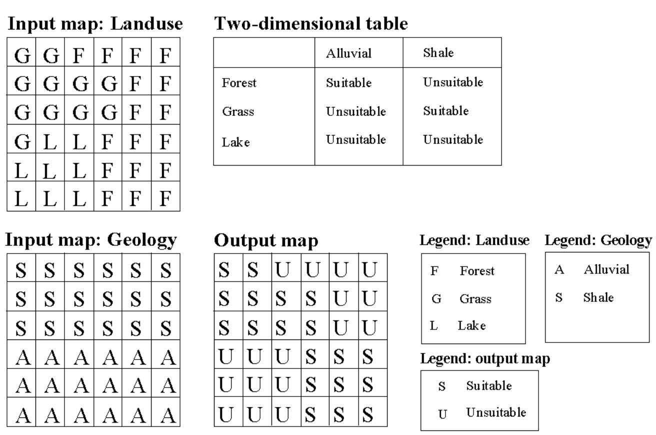
- For instance if we want to use the map Plan_curvature for the susceptibility analysis, we will convert the values into classes. Open the domain Susce_cassify. As you can see we have entered 4 boundary values to indentify the classes: high, moderate, Low and None.
- You can change these values after you have seen the distribution of the values in the map and have made the histogram (frequency table) for it.
- One you have made the right boundaries, go to Operations, Image Processing, Slicing, and select the map Plan_curvature, the output map S_plan_curvature and the domain Susc_classify
- Classify the value maps that you have selected as factor maps in the susceptibility analysis, and make separate class maps for it.



Option 1: Map crossing / joint frequency tables.

The idea is that you generate joint frequency tables of two maps, and in the resulting joint frequency table you can than fill in the classes of high, moderate and low susceptibility. You can do this pairwise (cross two maps at the same time). All input maps should be class maps, otherwise the number of combinations becomes too much. Also the class maps shouldn't have too many classes . The biggest advantage is that you as expert can decide for all combinations of all maps if they are susceptible as source area for the particular type of hazard you have selected. The result of the CROSS operation is a cross map and a cross table (joint frequency table). The figure on the left shows the principle of a cross operation. For the Barcelonette dataset we have already made a crosstable for you, by combining the factors: landuse, materials and slopes classes. We have added a column susceptibility, with four classes: High, Moderate, Low and Not susceptible.

- Open the crosstable Landuse_materials_slope by clicking the table icon in the Data Catalog. As you can see the table contains all combinations of landuse, materials and slope classes. The table also contains a column Susceptibility, which now only has the word "not". You can changes this by selecting the appropriate class when you click on it, or directly typing the first letter (e.g. H for high)
- In order to be better able to make the selection of the susceptible combination, you can change the sorting of the table (Columns, sort)
- Make your own selection of suitability classes and edit the column susceptibility.
- Close the table and right-click on the map Landuse_materials_slope. Select Raster Operations, Attribute Map. In the next window, select the column susceptibility, and name the output map also susceptibility. Click Ok.
- Open the susceptibility map that you just created and check if you agree with the pattern. Also check whether the existing hazardous events are in the high or moderately susceptible areas. Otherwise adapt the column susceptibility and make the attribute map again, until you are satisfied with the result.



Option 2: Two-Dimentional tables.

A two dimensitonal table is a matrix with which you can combine two class maps. The figure on the left gives the idea. The two dimensional table gives the user defined combinations of the classes of two maps. This is a bit more user-friendly than the crosstable, because you have to fill in less combinations. However, the disadvantage is that you can only look at the combination of two maps, and not more. In our case, we have made 3 two dimensional tables, that combine the maps **Landuse**, **Materials** and **Slope classes**. So: **Landuse_materials**, **Landuse_slopes** and **Materials_slopes** They all have the domain **susceptibility**, with High, Moderate, Low and None.

- Open the two-dimensional table Landuse_materials by clicking the table icon in the Data Catalog. As you can see the matrix contains all combinations of landuse, and materials. For each combination you should decide which Susceptibility class to select.

- Make your own selection of suitability classes.
- Close the table and in the command line type the following formula: **S1:=landuse_materials[landuse,materials]**
  This is the formula to apply the 2-D table landuse_materials to the maps landuse and materials and create an output map S1.
- Repeat this for the other 2 dimensional tables, and create the maps S2, from Landuse_slopes, and S3 from Materials_slopes

You can then combine the various individual susceptibility maps that you have created using another two-dimensional table: Susc_comb. This combines the classes in such a way that if one of the two maps is not susceptible the output maps is also not susceptible.

		Susceptibility map 1			
		High	Moderate	Low	None
Susceptibility map 2	High	High	Moderate	Low	None
	Moderate	Moderate	Moderate	Low	None
	Low	Low	Low	Low	None
	None	None	None	None	None

- Combine the individual susceptibility maps using the two-dimensional table Susc_comb.
  S4:=susc_comb[S1,S2]
  Susceptibility:=susc_comb[S3,S4]
- Open the susceptibility map that you just created and check if you agree with the pattern. Also check whether the existing hazardous events are in the high or moderately susceptible areas. Otherwise adapt two dimensional tables and make the attribute map again, until you are satisfied with the result.

Work out in your groups and define the susceptibility map for either: **landslides, debrisflows, rockfall, snow avalanches** or **flooding**.
The Susceptibility map contains the classes: High, Moderate, Low and None.

7.5 CHANGING THE SUSCEPTIBILITY MAP INTO SOURCE MAPS USED FOR RUNOUT MODELING

Now that you have made a susceptibility map the conversion into source maps for three events can be done, we do that according to the following table:

Susceptibility level	Hazard triggering event: source zones		
	Major event	Moderate event	Minor event
High	1	1	1
Moderate	1	1	0
Low	1	0	0
None	0	0	0

This means that if a major triggering event might produce mass movements in the areas designated as High, Moderate and Low susceptible. Small triggering events will only trigger mass movements in the Highly susceptible zones. We will now generate three maps

Open the three maps that you just created and check if you agree with the pattern.

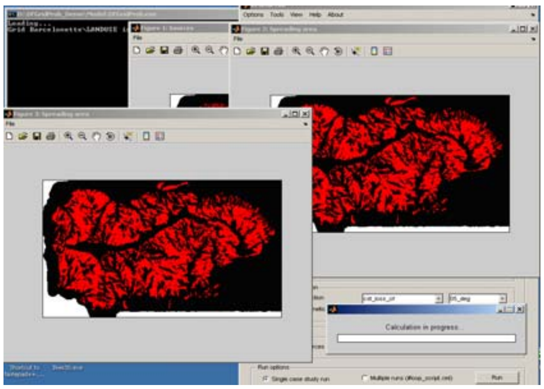
- Open the table susceptibility and check the data in the columns. We will now make maps from this using the attribute map operation.
- Select Operations, Raster Operations, Attribute Map. Select the input map Susceptibility, the Table Susceptibility, and the column: Major. Name the output map: Major.
- Do the same operation to generate the Moderate and Minor event source maps.

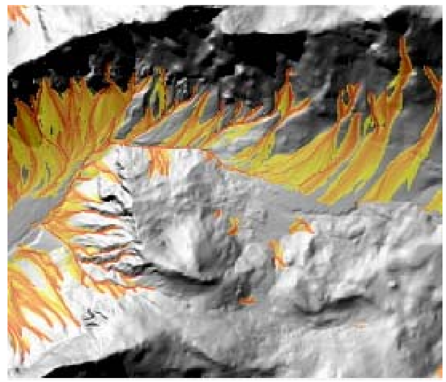
In case your map contains white areas, where a question mark appears when you click on them, these pixels have obtained so-called Undefined values. Undefined values are normal for the area outside of the study area. If they appear inside the study area then there is either a problem with one of the input maps (that might contain undefined values itself) or a problem in the operatuion that you perform.
If this happens always check with PixelInfo the maps that you used in the analysis, and read their values for the areas that are undefined in the output map. Try to find out what went wrong and repear the problem by adapting the analysis. You can also change undefined values in MapCalculation by using the **isundef(map) statement.** See also ILWIS Help for this.

The last step is to convert them to ARCInfo ASCII (.ASC) which is the format needed as input for the runout modeling that we will do in the next exercise with FLOW-R.

- Select File, Export, and select ArcInfor ASCII and the map Major. Name the output map also Major. Do this for the other two maps Moderate and Minor as well.

8 RUN-OUT HAZARD ANALYSIS ON A REGIONAL SCALE USING THE ROUTING-SPREADING MODEL FLOW-R





Expected time: 6 hours Software: Flow-R and ILWIS
Data: **Exercise_Barcelonnette_runout.zip** Size: 39 Mb
Objectives: Identification and modeling of the possible run-out spreading zones for different types of hazards, such as:

- shallow landslides
- snow avalanches
- debris flows
- rock falls

8.1 INTRODUCTION

In this exercise you will perform a simulation modeling different types of mass movements on a regional scale. The study site selected for this exercise is the "Barcelonette Basin" located in the Southern French Alps. The software to be used for the modelling is called Flow-R, a model developed in the University of Lausanne, Switzerland which runs in a Matlab environment. Flow-R is a deterministic, empiric model working with regular grids. The model approaches the hazard in two steps: the identification of sources or initiation areas for the specific hazard and the calculation of the spreading/run-out of the initiated failed mass.

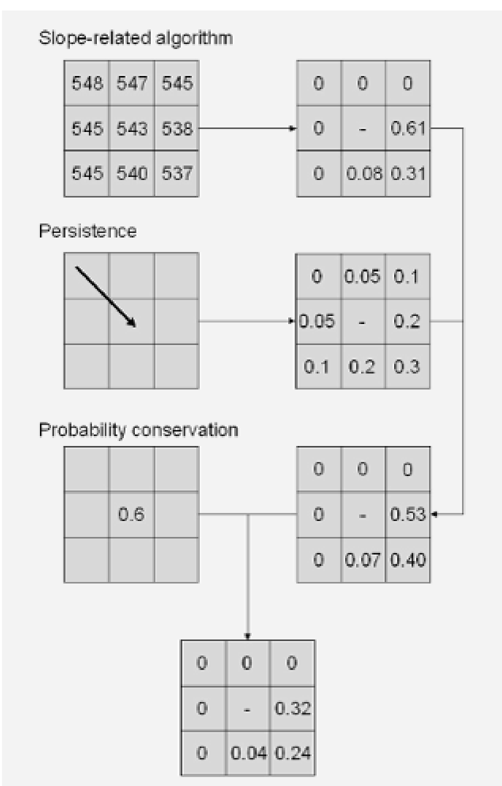
The exercise will consist of: Making a general estimation of the areas that might be affected in a Major, Moderate and Minor trigerring events usingthe Flow-R model.

The model can be used as a spreading/run-out model once the susceptible (sources) areas are already established in a site. The estimation of the spreading is based on basic probabilistic and energy calculations that allow defining the maximal run-out distance of a hazard. In this exercise we will show you how to use the software and give a brief explanation of the inputs needed to make a run. One of the aims is to give an insight of existing or potential new hazardous zones, by locating dangerous processes, without any notion of intensity or occurrence probability. This implies working on a whole region with limited data, in a GIS environment. The results will allow a quick overview of areas potentially reached by the specific threat. The model allows a transparent algorithm choice and an easy customization of the method. Thus, every algorithm is an external function that can be easily selected among others in the main graphical user interface. Each algorithm is then constrained to work on a grid basis. This approach is quite common in models for spreading assessment.

Input data in ARCInfo ASCII files (.ASC) for the identified source areas is needed to represent the spatial information of the susceptible areas. The source volumes are not taken into account in the calculation of the run-out.

8.2 THE FLOW-R MODEL

Flow-R is a simulation model developed with Matlab. It is a deterministic, empiric model with a regular grid. The identification of sources and spreading is conducted on a grid with a resolution chosen by the user. The criteria for identifying sources and the spreading algorithms and parameters are entirely established by the user.



The model conducts two distinct operations:

1) the identification of sources and 2) spreading. Although in this exercise we will only use the spreading module

1) Identification of sources:

Calculating sources is conducted by superimposing multiple grids of chosen data, subject to pre-determined selection criteria. Thus, each datum results in one grid where the cells are identified as sources in a binary grid (source – non source). For every datum, it is the slope that determines the trigger threshold

2) Spreading/run-out

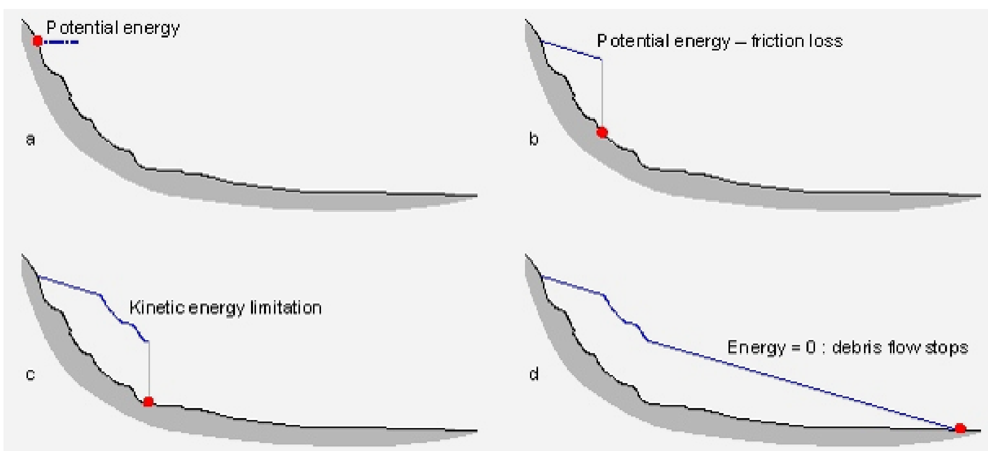
The model takes the results of the source identification and calculates the spreading zone for each source. The choice of spreading algorithms is conducted by the user. From one cell, each spreading algorithm results in the same type of result or the probabilistic distribution over 8 adjacent cells. These probabilities are thus spread along the lower slope, according to the criteria used in the selected algorithms.

The processes are the following: probabilities are first of all calculated by means of a spread algorithm, usually as a function of the slope. Then the persistence is determined (notion of inertia) as a function of the preceding direction of the flow and it is associated to the previous probabilities. This combination is then multiplied by the probability of the central cell, to be consistent along the spreading area.

The result is a surface covering all the cells that may be affected, along with the associated probabilities (see following figure).

The principle of energy calculations is introduced principally for calculating the distance obtained by the debris flow. The algorithms taking place are a function of friction losses and a limit to kinetic energy. Mass is not taken into account by the calculations and the energy calculations are applied to a unitary mass. There are obvious limits to this approach, but it avoids the need to estimate the mobile mass, information which is difficult to obtain for a large region.

The energy calculation is illustrated by the below example. At the start (a), a source has a certain energy potential. Then during the spreading, a part of this energy is dissipated according to the chosen algorithm (b). The limit of kinetic energy intervenes, if it is activated, from a certain energy threshold (c). The flow stops when the energy becomes zero (d).



For each cell, we thus have an energy value. One example is illustrated in the following figure.

The final results of the calculations are spreading zones with a notion of probability. As noted in the literature, the algorithms leading to these probabilities do not include established laws of probability. Probabilities should thus be considered qualitatively and not quantitatively, for example for establishing a colour code representative of the notion of danger for a map, but without being able to attribute frequencies or return periods.

The results are saved in ASCII files in ARCInfo format.

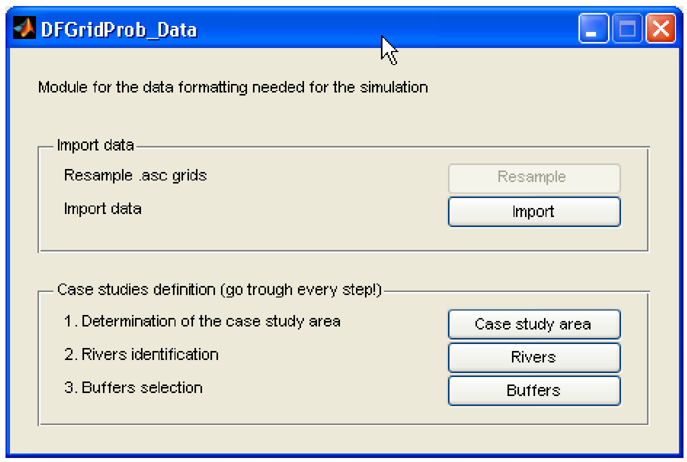
8.3 USING THE MODEL

The model consists of two main windows: the data preparation window and the simulation window.

Data preparation

Data preparation (Tools>Prepare data) is necessary in order for the model to function properly, as there is no data entry in the simulation interface. This is also where the study watersheds are defined.

Data entry is conducted using ASCII files in ARCInfo format, It is imperative that the cellsize be in metres. In addition, a constraint is imposed by the model: the reference coordinates for the grid must be a multiple of the grid size, in order to guarantee that the data are correctly superimposed



When the data have been entered, it is necessary to update the simulation interface to integrate the new data (Display> Update).

It is necessary that all the data be of the same resolution. The data resolution will influence the source identification as much as the calculation of spreading. All calibration effected on a certain resolution is not useable for another resolution. The resolution is to be established as a function of the study objectives.

Data importing and processing are conducted in two steps:

- The data are first imported using the button « Import ». This is where the ASCII grids are loaded. The spatial domain may be as large as you wish, as the study zones on which the calculations are effected are determined afterwards.

- Next, case studies are created. This step defines the sub-areas on which the calculations are effected. Actually, the size of study zones must be limited due to available memory. Data preparation consists of 3 steps; all are necessary:

- **Determine the study zone**: determine the sub-region to be studied. This creates a local grid of the digital elevation model (DEM) and a mask of the region. There are three ways to generate these data:

  - Manually using DEM: a sample of the DEM is displayed and the boundaries are defined by clicking on two points of reference.
  - By introducing the coordinates: boundary coordinates may be entered in a window. X corresponds to abscissa coordinates (West-East). Y corresponds to ordinate coordinates (South-North).
  - On the basis of a binary grid: a binary grid mask of the area in ASCII format of ArcGIS. The area to consider must be >=1 and the rest <=0.
  - By selecting the entire surface area of the DEM: this is only possible for areas of a reasonable size.
- **Identification of streams**: streams can be identified based on the "Flow Accumulation" calculated in ILWIS and imported in the regional data. It is also possible to effect calculations using an integrated routine, but this can only be done for an area of limited size
- **Choice of buffer zones:** only sources that are at a certain distance from the drainage zones will be taken into consideration. The size of the buffer (distance to drainage pixels) is to be determined. These buffers are not extremely precise, as they are squares. The result is a buffer mask in which the source of debris flows will be sought.

- To import the already created maps in ASCII format we use the "**TOOL**" directory and choose the **FORMAT DATA** subdirectory. A window is displayed which is the module for the data formatting needed for the simulation. We start importing the different attributes maps in the "**DATA**" folder that are inside the "**Barcelonnette input**" folder. It is good to remember that we are working in an ASCII format. We match the maps that we already have created according to the specification of the Grid type of the model. We enter the Region name "**Barcelonnette**". We can select the appropriate country projection. This is to be use with the KML shapefiles to be able to display the results in Google Earth. In our case, we will use the choice of "**OTHER**" projection since our work area is on the LAMBERT projection. We do the same procedure with all the other maps being careful to use the same region name all the time.

- Once the loading of all the maps is done we will define the case study area. For this we click on the "**case Study area**". The option of choosing several methods is displayed. The option "**manual on the DEM basis**" allow us to define inside the DEM with a rectangle polygon the area we are interested in working with. Other options to size and area of the study area are "by **giving coordinates**", "**based on binary grid**" and in our case, we will choose to "**select the whole DEM area**". Here we choose the "**Barcelonnette**" option and we give a Case Study Name.

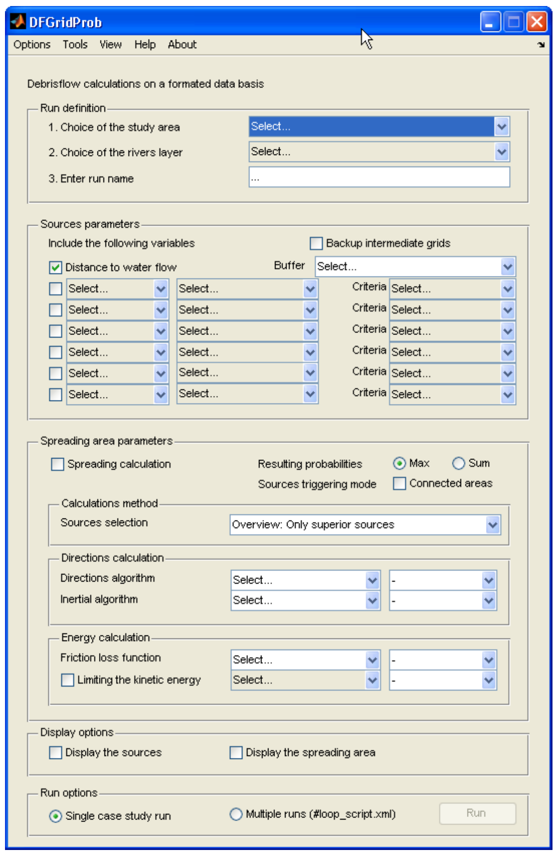
- After choosing the study area we will identify the rivers inside our study area. This areas are chosen for their importance in the processes since usually rapid mass movements follows flow accumulation paths in the terrain. For this we will choose the case study area we created. A window will be displayed, asking if we want to identify the waterways for identification. We click on yes and a new window appears where we have to the option of applying the flow accumulation map (that we already created before and loaded) or let the software create and calculate this. In our case we will choose "to load the already existing ASCII data". A minimal flow accumulation area is considered for trigerring an event. This area should be defined ain Hectars. This is the amount of area that will contribute to the source. In our case we will chose 1 hectar contributing . The upslope contributing area is taken into account as a characteristic of water input. A new window asking for a suffix in the case study name is displayed. We choose the default suffix.

- If desired a buffer for the waterway can be selected. In our case we will generate a buffer for the sources identification. We will use a 10 meters as buffer meaning that all the sources has to be 10 meters from the waterway to be a contributing source. A window asking for a suffix to the buffer in the case study name is displayes, We will use the deault suffix.

Simulations

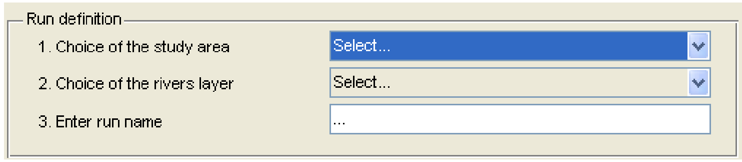
The model has two principal function modes: the simulation of a simple case or a script run with multiple simulations. In simple simulation mode, the interface is the following:

During a study of an area, it is necessary that all the data be of the same resolution. The data resolution will influence the source identification as much as the calculation of spreading. All calibration effected on a certain resolution is not useable for another resolution. The resolution is to be established as a function of the study objectives.



The model inputs are:

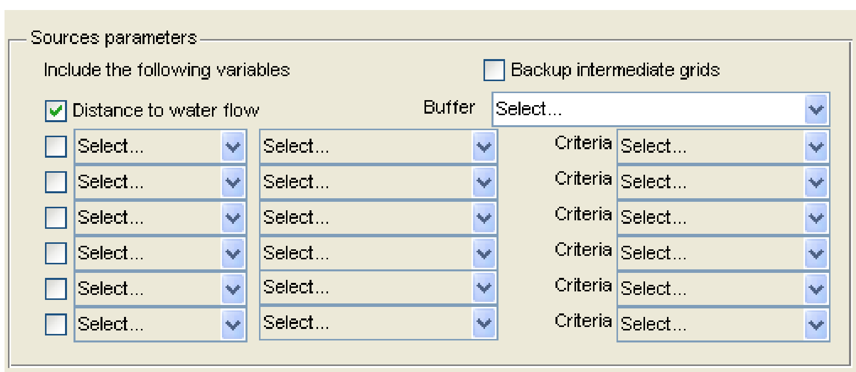
- Simulation definition: corresponds to the choice of the sub-area to be studied. The pre-formatted data appear in the dropdown menus.



- The study zone: corresponds to the name of the sub-area.
- The river mask: corresponds to the stream mask (pixels with a contributing area above the threshold limit).
- The run name: a name attributed to result folders. It is necessary to give a run name to activate the “run” button.

- Once the data formatting is over. We close the Module of importing data. Now we will define the “**Run definition**”. First we choose the study area. If you can not find it, it is necessary to update the simulation interface to integrate the new data clicking on the “**Display**” directory and selecting on “**Update**”. Select the choice again and select the option **Barcelonnette**. Next choose the rivers layers that are already created in our case will be “**Barcelonnette_ca1ha**”. We need to define a name for the run-simulation. In our case we will choose “**Barcelonnette**”.

- Source parameters: This section defines the data and the criteria to be considered for the source identification.



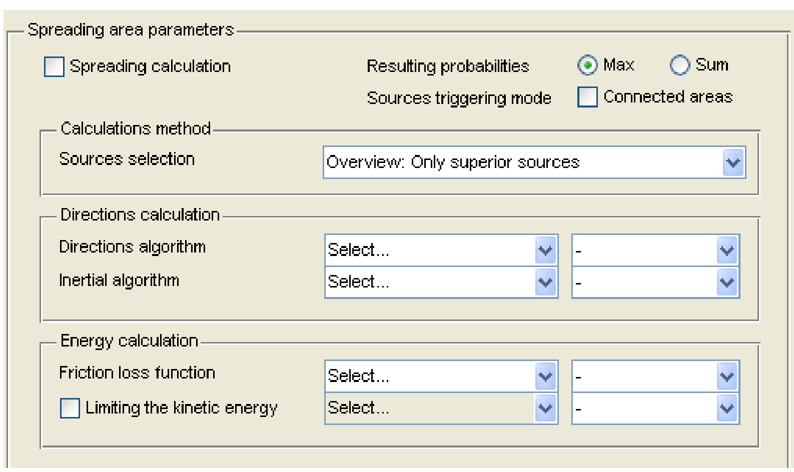
- Each combination of data and criteria determine the starting pixels of debris flows, neutral pixels and excluded pixels (details). The selection represents the intersection of source pixels (or neutral pixels) of different data. The options are:

1. The buffer mask around drainage zones can be activated or deactivated. Buffer choices are those which have been prepared with the routine data update.
2. The user can chose up to 6 different data sets by selecting from dropdown menus. The second dropdown menu is the area for which this type of data is available. The third menu lists the criteria used on different variables for

identifying source pixels. These criteria are described in the xml files of the folder parameters\ sources and can be modified.

- We click and select the **back-up intermediate grids**. Then we select the "**distance to the water flow**" box and load the file in the "**Buffer**" section. We will select the river layer already created with the designed suffix.
- Now we will upload the source-initiation map maps that will contribute to the spreading areas.
- We select the "**Sources**" and select the map inside our study area "**BARCELONNETTE**". We choose the criteria "**BOOLEAN**". This criteria indicate us that the source areas will have a value of one and the rest of the DEM will have a value 0. The model will only take into account the source areas for the run-out calculation.

- Spreading parameters: the activation of spreading calculations and the choice of algorithms are available in this section.



1. The first option is to **activate / deactivate the spreading calculations**.
2. The second is a **choice for the resulting probabilities**. One can either save the maximum for each cell, or sum up its probabilities. This last option requires simulating each spreading entirely, which can turn into a lengthy process.
3. **Calculation modes**: there are 4 different calculation modes that require more or less time:
   - **Overview**: only superior sources - > An automatic identification allows to extract the highest sources in each buffer. During this synopsis, only these superior sources are triggered. These results are generally good, but rarely complete.

- **Quick**: selective according to energy - > As for the preceding option, superior sources are triggered first. Then the other sources are considered and during the spreading calculation, if another debris flow has taken the same trajectory (pixel) with a similar of superior energy, the calculations of this pixel will stop since they are likely to be redundant. This selection according to energy is very efficient; it can save a lot of time and produces results quasi similar to the full simulation for each source. This option is highly recommended.
- **Intermediate**: selection according to energy and direction - > This principle is the same as the preceding option but tests are in addition effected on the direction of the debris flow. Thus, calculations are stopped if the energy is similar or superior for the same direction. This option slows down calculations considerably, yet it remains faster than a complete simulation of all sources.
- **Complete**: simulation of all debris flows - > Each pixel source is spread without conditions. This can be extremely time consuming!

- The debris flow spreading can be mathematically estimated by two types of algorithms: the first ones are called flow direction algorithms and rule the path that the debris flow will follow; the second ones determine the runout distance. We select by clicking the box of "**spreading calculation**". We select the also on the options of "**resulting probabilities**". Max probability is basically the maximum probability of spreading reached in the pixel from all the flows from the sources above, on the contrary the sum is the just the sum of the probabilities from the above sources. In our case we choose the **MAX probability**.

- **Direction calculations**: choice of direction algorithms and inertia algorithms (or persistence). Different parameters are applied for the selected algorithms. These can be chosen from the dropdown menu on the right. These parameters can be modified.

- Now we select which method of calculation we use for the direction of the flow. Flow direction algorithms apportion the flow from one cell to its eight neighbors. Some conditions are defined so that there is always at least one cell in which the flow can run, so that run-out distance algorithms only determine if it flows further or if it stops. We click on the directions algorithm selection. Various flow direction algorithms have been integrated. In our case we will chose **Holmgren's algorithm**, for its best fitting with occurred debris flows events in the past. **The exponent is set to 4.**

- The final probabilities are function of the slope (directions algortihtms) and the persistence (inertial algorithms), which is a weighting of the directions according to the previous direction, allowing an integration of the notion of inertia. Debris flows behavior on fan-like terrain, with low slope gradients, is best represented by a probability function. It is, however, not a mathematical probability in a strict sense, but it has to be to be interpreted in a qualitative way. To be able to compute the final probabilities we have to select the **"Intertial Algorithm",** in our case we choose the "**WEIGHTS**". Based on Gamma (2000), the weight is a function of the change in angle from the last flow direction. In our case we will choose the "**DEFAULT weighting**".

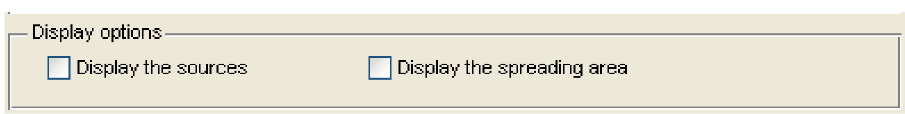
- **The friction loss function**: determines the energy loss as a function of different parameters. These parameters can be modified.
- **Kinetic energy limits:** introduces a superior energy threshold (in m/s). This threshold can also be modified.

  - For the run-out calculation we will include the **ENERGY CALCULATION**. Runout distance algorithms are basic energy-based calculations that define if a part of the debris flow can potentially reach another cell. They control the distance reached by the debris flow. In that way, the energy-based algorithms also influence the flow direction. Although the source mass is unknown. Thus, runout distance calculation is based on a unit energy balance, a constant loss function and a maximum threshold.

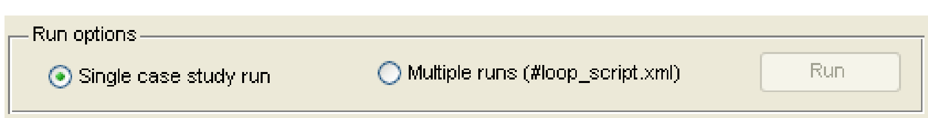
  - The average slope is the slope between the starting and end point following the debris flow path. So we considered a "**Constant Friction Loss**" corresponding to the angle of the slope. This would result in a runout distance equal to the probable maximum runout. In our case we will choose a **15 degree angle**.

  - Next we will click on the box where the option "**Limiting the kinetic energy"** is located. This is the maximum threshold to limit the debris flow energy to reasonable values. In our case we chose the threshold to a **maximum velocity of 15 m·s-1.**

- Display options: Allow an overview of selected pixels as sources and an overview of spreading zones. It is highly inadvisable to activate these displays during a calculation of a large area, as they would increase the calculation time considerably.



- Run options: As explained in the beginning of the section « Simulations », a choice is possible between the simulation of a unique case, as we have just described, or a script run allowing to simulate different areas or different configurations consecutively (variables, parameters, algorithms).



- We select the both boxes in the **Display options**. This will display the calculated sources and also the calculated spreading area.
- In the run option we select the box **"Single case Study run**" and we click on the **"RUN"** button to make the model run.
- You will be able to see a display of a map where the Sources areas are calculated and a map where the Spreading areas. There will be a window indicating the progress of the calculation
- After the run has finished. You can go to the folder "**MODEL"** and check inside the folder **"RESULTS**". You will find the folder **"BARCELONETTE**". Inside the folder you will find three ESRI/ARC ASCII files and .png files. When exported into a GIS this files will display the **Kinetic Energy**, the **Probability** and the **Sources**. If you want to display your results in a fast way, you can open the .png files in any photo editor.

8.4 CALCULATION OF SPREADING AND RUN-OUT

According to the scientific literature, the angle reached by moving masses depends on the volume: the higher the volume, the lower the angle of reach and thus the further will the masses moves

- Vary the angle coefficient and the velocity thresholds. The values to be changed are mentioned below. If you think the below mentioned angles do not fit with your hazard, you can calibrate the value.

Parameter	**Values**
Friction loss angle	5° 15° 30°
Velocity threshold	5m/s 15m/s 30m/s

8.5 IMPORTING THE ASCII RESULTS MAPS TO ILWIS

Inside the folder "results" you will find the directory with the name of your run. In this directory you will have three different ASCII files.

Type of output file	**Content of the data**
Ekin.asc	Map with the calculated kinetic energy of the spread mass
Prob.asc	Map with the calculated probabilities of the routed mass
Sources.asc	Map of the source areas

- Import this ERSI_ARC files into ILWIS. Save the three different output maps _Ekin as **Major_Ekin, Moderate_Ekin, and Minor_Ekin.**

8.6 IMPORT THE OUTPUT MODEL RESULTS TO "IMPACT PRESSURE" MAPS

Use the following relationship to estimate the velocity from the kinetic energy outputs maps of the model using a unitary mass.

$$KE = \frac{1}{2} * m * v^2$$

With: ***KE*** Kinetic energy resulting from the model
m Mass (unitary)
v Velocity

Pressures can be found using the bulk densities of the mobilized materials and its velocities.

Type of event	Bulk Density (kg/m3)
Debris flows	1850 - 2200
Snow avalanche	200 - 350
Landslides	2150-2600
Rockfall	2400 -2700

- Compute a "**impact pressure map"** for each class of susceptibility map that you have created.
- In the ILWIS softaware, use the "**Map calculation**" inside the "**Raster operations**". In the "**Expression**" section, you can define the relation for the velocity, density and the modelled kinetic energy. You can define the **"Expression"** as:

((sqrt (2 * Major_Ekin)) * Bulk density) /1000

((sqrt (2 * Moderate_Ekin)) * Bulk density) /1000

((sqrt (2 * Minor_Ekin)) * Bulk density) /1000

- Name your maps as **Major_runout, Moderate_runout, and Minor_runout** for the 3 different triggering events.
- Use the "**value**" in the "**domain**" section.
- The result will be three different impact pressures maps in KPa (kilopascals) that will be used to calculate the hazard and risk analysis.

o What are the main different characteristics that you observe in your scenario maps?

- How can these scenarios maps be used in a risk assessment?
- If you would be a decision maker, how would you categorize these maps?

  - Save your three impact maps created. Check that they should be named **Major_runout, Moderate_runout, and Minor_runout**.

8.7 DISCUSSION

- As mentioned before, the model gives also as an output a map with calculated probailities. Convert this maps in ARCInfo ASCII into ILWIS and observe its features.
- **Comment and discuss with your group members what the meaning of this probability map is. Can you describe the outputs values?**
- In this exercise, a Holmgren routing algorithm was chosen because it fits reasonable with convergent flows. This convergence does not always happen in other types of hazard. A small description of the routing algorithms is presented below:

  - The **D8 algorithm**, which assigns the flow to only one adjacent cell it is limited to directions of 45°

  - The **D∞ algorithm**, which assigns the flow to one or two adjacent cells, increasing the D8 performance

  - **Fairfield and Leymarie (1991)** introduced a stochastic method called ρ8, which gives a probability to every cell having an altitude inferior to the central cell. The path is randomly determined afterwards, producing a single flow direction

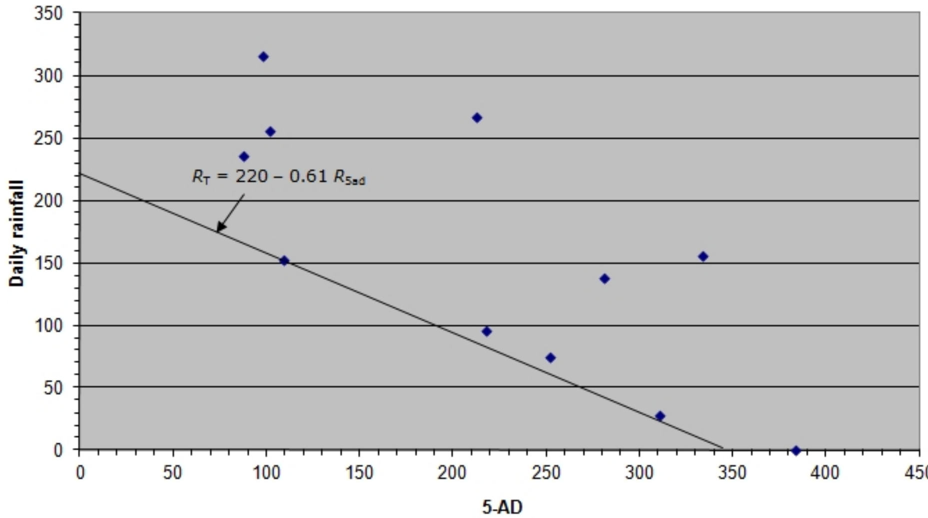
  - The **basic multiple flow direction method (Quinn *et al.* 1991)** is based on the previous method and considers the spreading over every non-zero cell in a continuous, and not random, way.

  - Freeman (1991) developed some variants of the basic multiple flow direction algorithm, but without introducing noticeable changes.

  - **Holmgren (1994)** introduced an exponent in the algorithm, with an optimal value between 4 and 6. The higher is the exponent, the more convergent the flow becomes.

- If time permits, you can change the different routing algorithms to observe which one fits better to your type of hazard. Observe the differences between the different algorithms and discuss with the members of your group which is your choice and why.
- For what type of hazard and which situation will you use the different algorithms defined in the model?
- Shallow landslides, Debris flows, Snow avalanches, Rock falls?

9 RAINFALL-THRESHOLD BASED TEMPORAL PROBABILITY ANALYSIS OF LANDSLIDING: CASE STUDY NIGIRI, INDIA



Expected time: 3 hours
Data: **Exercise_Nilgiri_thresholds.zip** Size: 0.5 Mb
Objectives: Analysis of rainfall thresholds, using relation between daily and antecedent rainfall using Excel data.

9.1 THEORY

For rainfall induced landslides an indication of the temporal probability of landsliding can be obtained by evaluating the temporal probability of the rainfall events themselves combined with an analysis of the rainfall-thresholds, which is the minimum intensity or duration of rainfall required to trigger a landslide (White et al., 1996; Crozier, 1997; Reichenbach et al., 1998). Such an analysis requires information on the actual dates of occurrence of landslides and corresponding rainfall data, which can be obtained from historical records. *The assumption is that the rate of landslide triggering events and landslide occurrence will remain the same in future under the given geo-environmental conditions.*

Rainfall thresholds for landslide initiation can be estimated using empirical methods.. Empirical methods are based on the estimation of rainfall thresholds obtained by studying rainfall conditions that have resulted in landslides. They are usually contained in envelope curves based on variables such as antecedent rainfall, rainfall intensity and rainfall duration (Glade, 1998; Chleborad, 2000; Aleotti, 2004; Jakob et al., 2006).

In next sections, I propose a method to determine the temporal probability for landslide events using the probability of exceedance of an empirically derived rainfall threshold and the probability of occurrence of landslides related to the rainfall threshold.

7.1.1 Methodology for temporal probability assessment

The input of the rainfall threshold analysis is the time series of daily rainfall $R_d(t)$ in mm day^{-1}, where t is time. For a landslide (L) to occur, the daily rainfall must exceed a threshold, which is a function $R(t)$ of the daily rainfall in a period, and of the amount of the antecedent rainfall $R_{ad}(t)$, i.e., rainfall that have occurred prior to the day of landslide occurrence.

$$R(t) = f[R_d(t), R_{ad}(t)] \quad (1)$$

where $R_{ad}(t)$ is the antecedent rainfall in mm. This function of R defines the probability of occurrence of the landslide L: P(L). If R_T is the threshold value of R then,

$$P[L|(R > R_T)] = 1 \text{ and } P[L|(R \leq R_T)] = 0 \quad (2)$$

Thus, in this simplified model, landslides always occur when R exceeds R_T and does not occur when value of R is lower than or equal to R_T. In the former case, the probability of occurrences of landslide P(L) depends on the exceedance probability of P($R > R_T$), i.e., P(L) = P($R > R_T$).

In reality, however, the threshold may be exceeded without resulting in any landslide. This may be attributed to some other factors which locally influence the initiation of a landslide and are not fully understood (Aleotti and Chowdhury, 1999). This difference can be reduced when the final probability is viewed as the conditional probability of a given threshold exceedance P($R > R_T$) and the probability of occurrence of a landslide P(L), given the exceedance (Lee and Jones, 2004; Floris and Bozzano, 2008). Thus, the probability of landslide occurrences can be given by the intersection of two probabilities,

$$P[(R > R_T) |L] = P(R > R_T) \times P[L|(R > R_T)] \quad (3)$$

This means that the probability of occurrence of both ($R > R_T$) and (L) is equal to the probability of ($R > R_T$) multiplied by the probability of occurrence of (L), assuming that ($R > R_T$) has already occurred. The probability of ($R > R_T$) can be obtained by determining the exceedance probability of the rainfall threshold and the probability of $[L \mid (R > R_T)]$ relies on the frequency of occurrence of landslides after the threshold has been exceeded.

The above assumption that landslide have to occur whenever a given rainfall threshold is exceeded may not hold always and everywhere. However, it is also expected that landslides will not occur below the rainfall threshold. Hence, for rainfall-triggered landslides, this assumption can be an acceptable first-approximation to work with and to estimate the frequency of landslide events by establishing relations between the landslide trigger, its magnitude and the occurrence of the landslides.

9.2 DETERMINATION OF THE RAINFALL THRESHOLDS

Methodology for determining rainfall thresholds

To determine the rainfall thresholds a threshold model based on antecedent rainfall is selected because of the availability of daily rainfall data.

Depending on the type of landslides and their geo-environmental setting, the number of antecedent days can vary from 3 days for shallow landslides to 30 days for deep landslides (Kim et al., 1992; Aleotti, 2004; Zezere et al., 2005; Chleborad, 2006). In this case study 5-days antecedent rainfall is considered suitable for the analysis of the shallow debris slides.

To determine R_T, a scatter plot is prepared showing daily rainfall (y-axis) against the corresponding 5-day antecedent rainfall (x-axis), for each day with one or more triggered shallow landslides. The envelope curve is manually drawn such that it demarcates the lower end of the plotted points. The line can be represented by a linear mathematical equation (Crozier, 1999; Chleborad, 2000).

Validation of the threshold model

Validation of the threshold model can be done using rainfall and landslide events that occurred after the period considered in the modeling. The obtained threshold equation can be used in excel to find out the R_T, for different antecedent rainfall. A plot can be generated taking the difference of daily rainfall R and R_T (threshold exceedance) on the y-axis and corresponding date on the y-axis. Between two successive positive periods (i.e., the period for which the threshold was exceeded) there may be a period with no rainfall or very low rainfall. Each rise in the threshold curve indicates that either there is a sudden increase in the magnitude of daily rainfall or there is a constant rise in five days antecedent rainfall. The width of each positive curve (or positive amplitude) denotes the period of consecutive rainy days in a given month. The crossover of the curve from negative to positive values indicates the time when the threshold is crossed and the conditions favourable for landsliding begins. One or more landslide events should occur in the validation data before the positive curve decays to the zero threshold value.

Determining temporal probability

The annual exceedance probability (*AEP*) is the estimated probability that an event of specific magnitude will be exceeded in any given year (Fell et al., 2005). For a given rain gauge *AEP* of the threshold $P(R > R_T)$ was determined using a Poisson probability model. This model has been used to determine the exceedance probability of landslides in time by, e.g., Coe et al. (2000, 2004) and Guzzetti et al. (2005). According to the Poisson model, the exceedance probability or the probability of experiencing one or more landslide events during time t is given by

$$P\left[N(t) \geq 1\right] = 1 - \exp\left(-\frac{t}{\mu}\right) \quad (4)$$

where μ is the mean recurrence interval between successive landslide events, which can be obtained from the multi-temporal landslide inventory data.

To determine *AEP* of the rainfall threshold, R_T is calculated from the threshold equation, and the result is subtracted from R. Each phase of continuous positive values ($R > R_T$) is considered as the period of maximum likelihood for landslide initiation.

The next step after calculating *AEP* of the rainfall threshold is the assessment of the probability of landslide occurrence after the threshold has been exceeded. The frequency can be established from the rainfall and landslide records. From this frequency, the probability of (L) conditioned on ($R > R_T$), i.e., $P[L|(R > R_T)]$, can be estimated.

As indicated earlier, the temporal probability of landslide initiation was calculated by multiplying:

(i) *AEP* of the rainfall threshold, i.e., a probability of the threshold being exceeded in a year, by

(ii) the probability of landslide initiation given that the threshold is exceeded $P[L|(R > R_T)]$.

9.3 EXAMPLE OF THRESHOLD-BASED TEMPORAL PROBABILITY ANALYSIS

Description of data set (excel file name: Example_Threshold)

The data set belong to Nilgiri hills, Tamilnadu, India. The area is a transportation corridor encompassing a 24 km long section of a road and a 17 km long section of a railroad. Geologically, the area exposes charnockite rocks overlain by lateritic soils. The sub-tropical climate and intense physical and chemical weathering have resulted in a thick yellowish to reddish brown soil. The overburden thickness (including weathered zone) varies from less than a meter to about 20 m.
Landslides are very common events in the Nilgiri area, which occur mostly as debris slides or debris flowslides triggered by high intensity or prolonged rainfall on cut slopes. Most of the landslides occur during November. This month also receives the highest rainfall each year due to the NE monsoon, which starts on October and ends on December. An inventory of a total 932 landslides was prepared from historical records, including information on the date of landslides, volume and location. Out of these more than 90% occurred due to NE monsoon between the period October and December.

To determine the rainfall thresholds, only shallow translational cut slope failures along the railroad were selected that occurred from 1992 to 2006 in the period from October to December. The reasons for this were: (i) the majority of landslide events have occurred between October and December, (ii) the date of all landslide events is known only for the period from 1992 to 2006, and (iii) the railway records contain information on all landslide events that occurred in the study area A threshold model based on antecedent rainfall was selected because of the availability of daily rainfall data, and also due the fact that in future recording of daily rainfall is cost effective and the model is easy to implement.
Since the number of landslides and the rainfall condition vary along the transportation corridors, therefore for the calculation of the thresholds the transportation corridor was divided into four sections (Figure 1), based on topography, land use types, and terrain gradient. Rainfall conditions at each section were determined from the nearest rain gauge.

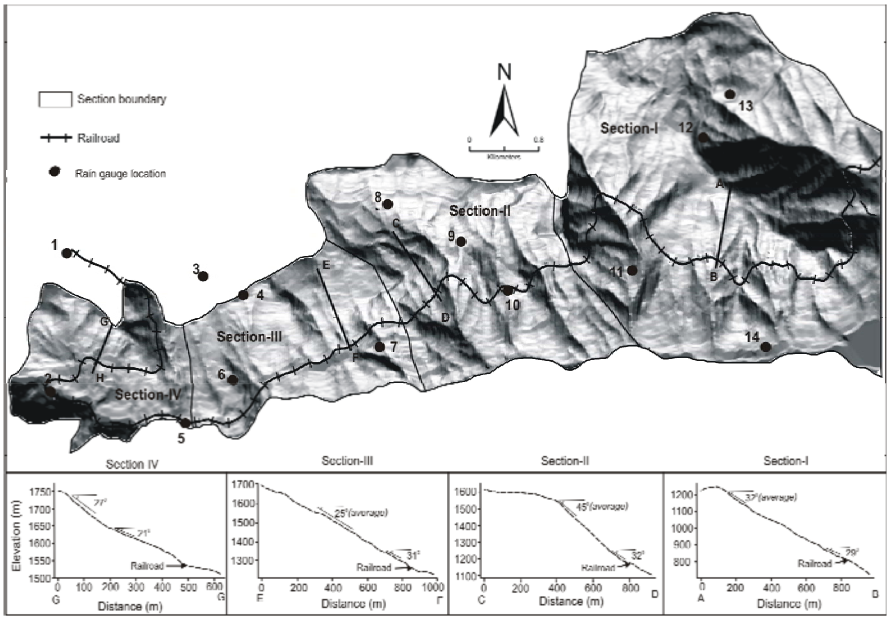


Figure 1 *Location of sections and rain gauges for determining rainfall thresholds: 1- Coonoor, 2- Glandale, 3- Upassi, 4- Tiger hill, 5- Runneymede, 6- Katteri farm, 7- Marapallam, 8- Singara_UD, 9- Singara_LD, 10- Hillgrove, 11- Burliyar, 12- Adderley, 13- Mutteri and 14- Kallar farm. Sections I, II, III and IV are the areas used for determining rainfall thresholds. Their corresponding terrain profile is shown in boxes.*

In the excell file (name: **Example_Threshold**), data of landslide events within section-II (Hillgrove rain gauge) is given (refer excel sheet: slide data). A total 17 events with the number of landslides triggered within section-II is given for the calibration of threshold (1992-2006). Also data of 4 landslide events (2008 and 2009) for validation is given. Sheet (rainfall data) contains the daily rainfall for the period from 1987 to 2009 from Hillgrove rain gauge. Now this information will be used to obtain envelope curve for the minimum threshold require triggering landslides within section-II of the transportation corridor.

Consider only the period for NE monsoon (i.e. from October to December) for the calculation of temporal probability.

9.4 METHOD FOR GENERATING ENVELOPE CURVE FOR THRESHOLD ANALYSIS

1. Open excel file (name: **Example_Threshold**). Look into the data. The sheet (**Slide data**) contains list of 17 landslide event dates. The sheet (rainfall data) contains daily rainfall from Hillgrove rain gauge.

In case of sl no 7 and 8, there is no information on rainfall. We can use the nearby rain gauge also if rainfall actually occurred on these days but not recorded due to some reasons.

2. Calculate 5-days antecedent rainfall for each year as shown in the excel sheet (name: antecedent). For 5-days AD, add the previous 5 days of daily rainfall. Example, the 5-AD for Jan 6th will be sum the of daily rainfall of Jan 5th to Jan Jan 1st. In the example only 5-AD of 1992 is shown.
3. List out the daily rainfall and the corresponding 5-AD rainfall for the 17 landslide event days. The result is shown in column E and F of sheet (name: slide data).
4. Draw a graph (chose scatter plot) taking daily rainfall in y-axis and 5-AD in x-axis. The result is shown in sheet (name: slide data). Draw a line "manually" such that it demarcates the lower end of the plotted points and extend it up to the x and y axis.

In a few cases, landslides were also reported when no rainfall was measured on any specific day. These were the cases when high antecedent rainfall alone has resulted in landslides, due to water percolating from upslope areas. Thus, for all the listed thresholds, the lower boundary of the envelope curve was set to zero daily rainfall.

5. The line is a straight line with negative slope of the type y=-mx+c, where m is the slope and c is the intercept. Compute the equation for the line (hint: m= y_2-y_1/x_2-x_1). For this line the slope is given as 1.32 and the equation can be written as $R_T = 165 - 1.32\ R_{5ad}$.

9.5 VALIDATION OF THE THRESHOLD MODEL

1. Select daily rainfall data for the period from Oct to Dec for 2008 and 2009 (please note that the model is developed using landslide events between 1992 and 2006).
2. Arrange the rainfall data in one column (as in Column C, sheet "validation"). Calculate 5-AD in column D (name: 5-AD). Solve the threshold eq. ($R_T = 165 - 1.32\ R_{5ad}$) in column E (name: Threshold rainfall) and in column F subtract this value with the daily rainfall (name: Threshold exceedance, which is column C-column E).
3. Chose scatter line graph and plot a graph taking date on x-axis and Threshold exceedance on y-axis separately for 2008 and 2009 (the two graphs are shown in sheet: name 'validation'). See what the graph indicates.

The graphs indicate that in the period from October to December the rainfall has exceeded the threshold curve two times each year. In 2008, the threshold was exceeded on two occasions (between 12 and 16th Oct and between 21 and 27th Oct 2008) and landslides were found associated with 16th and 21st October. Similarly, in 2009 the threshold was exceeded on two occasions and landslides were associated with the rise in the threshold curve between 8 to 15 Nov 2009. In contrast to 2008, peaks of 2009 are associated with high magnitude daily rainfall and therefore as expected more number of landslides occurred in 2009. The figures also indicate that landslides are not always associated with the rise in the threshold curve e.g., between 23 to 26 Nov 2009. This could be due to the variation in the pore pressure resulting from changes in the amount of antecedent rainfall.

9.6 DETERMINING TEMPORAL PROBABILITY

1. Select daily rainfall data for the period from Oct to Dec for 1992 and 2006 (please note that the model is developed using landslide events between 1992 and 2006, so total number of year N=**15**).
2. Arrange the rainfall data (from 1992 to 2006) in one column (as in Column C, sheet "threshold exceedance"). Calculate 5-AD in column D (name: 5-AD). Solve the threshold eq. (R_T = 165 – 1.32 R_{5ad}) in column E (name: Threshold rainfall) and in column F subtract this value with the daily rainfall (name: Threshold exceedance, which is column C-column E).
3. Count the number of times the threshold was exceeded in the 15 years between Oct and Dec (1992-2006). You can count using the graph or simply count the number of continuous positive values in column F (i.e., group of positives bounded by negative values). [consider it as the mean recurrence interval between successive landslide events , μ , which here is **29**].
4. Now solve equation (4) i.e., the Poisson model for the exceedance probability. In sheet name: Threshold exceedance, the equation is solved in column L52 (click on L52 and look at the relation). This is solved for t=1 year (i.e., annual exceedance probability). You can substitute any value for t, say 5, 10 or 50 and can calculate the probability of exceedance in any value for t year.
5. The next step after calculating *AEP* of the rainfall threshold is the assessment of the probability of landslide occurrence after the threshold has been exceeded i.e., $P[L|(R > R_T)]$. This is simply the number of times landslides have occurred when the threshold was exceeded in the 15 years, which here is 14 divided by the number of times the threshold was actually exceeded, which is μ = 29. Thus $P[L|(R > R_T)]$ is 14/29 = 0.48.

Finally the final probability $P[(R > R_T)\ |L]$ can be calculated as using Eq (3), as shown in column M61 (sheet: Threshold exceedance). This is simply the multiplication of the exceedance probability and $P[L|(R > R_T)]$.

$$P[(R > R_T)\ |L] = P(R > R_T) \times P[L|(R > R_T)]$$
$$= 0.86 \text{ for t=1 year} \times 0.48$$
$$= 0.41$$

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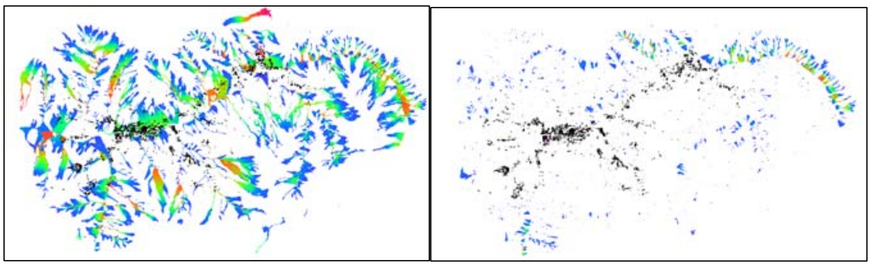
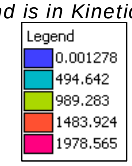
10 MEDIUM SCALE MULTI-HAZARD RISK ANALYSIS FOR MASS MOVEMENTS: THE BARCELONNETTE CASE STUDY



Example of two runout maps for one of the processes for a Major and Minor event. Legend is in Kinetic



Expected time: 6 hour
Data: **Exercise_Barcelonnette_Risk.zip** Size : 527 Mb
Note : the zip file contains 5 other zip files. Unzip the file: Data_exercise_3A.zip which contains all the main files. Then select whether you want to work with landslides, rockfall, snow avalanches, or debrisflows, and unzip the respective zip file.
Objectives: After this exercise you will be able to:

- Convert the output maps of runout modeling into hazard maps by assuming temporal, magnitude spatial probability
- Evaluate the elements at risk informaton
- Overlay the hazard maps with selected elements at risk and generate risk information

10.1 INTRODUCTION

In the previous exercises you have made within your group an evaluation of the source areas for either Snow avalanches, rockfall, debris flows or landslides, and you have used the FLOW-R programme to make a general estimation of the areas that might be afffected in Major, Moderate and Minor triggering events.
This exercise shows you how we can evaluate the exposed elements at risk, such as buildings, landuse, roads, powerlines, and skilift. Also an evaluation can be made of the people at risk.
We now would like to use the information to estimate the risk. We will do that following the following basic equation:

Risk = Hazard * Vulnerability * Amount of elements-at-risk

The equation given above is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk from hazards. The way in which the amount of elements-at-risk are characterized (e.g. as number of buildings, number of people, economic

value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g. annual probability).
For calculating risk quantitatively using equation 1 the vulnerability is limited to physical vulnerability of the elements-at-risk considered, determined by the intensity of the hazard event and the characteristics of the elements-at-risk (e.g. building type). Table 1 gives a more in-depth explanation of the various components involved.
In order to calculate the specific risk equation can be modified in the following way:

$$R_S = P_T * P_L * V * A$$

in which:

- $\mathbf{P_T}$ is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area;
- $\mathbf{P_L}$ is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk. ;
- **V** is the physical vulnerability, specified as the degree of damage to a specific element-at-risk E_s given the local intensity caused due to the occurrence of hazard scenario H_S
- **A** is the quantification of the specific type of element at risk evaluated. It is important to indicate here that the amount can be quantified in different ways, and that the way in which the amount is quantified also the risk is quantified. For instance the amount can be given in numbers, such as the number of buildings (e.g. number of buildings that might suffer damage), number of people (e.g. injuries/ casualties/affected), the number of pipeline breaks per kilometre network, etc. The elements at risk can also be quantified in economic terms.

In order to evaluate these components we need to have spatial information as all components of the equation vary spatially, as well as temporally. The temporal probability of occurrence of the hazard scenario (P T) has also a spatial component. For example a flood with a given return period has a certain extension, and spatial variation of intensity. The equation also contains a term (P T) indicating the spatial probability of occurrence and impact. This is not relevant for all types of hazards, and in many cases this probability can be indicated as 1, given a specific hazard scenario (e.g. the area that will be flooded given a return period of 50 years). However, for other types of hazards, such as landslides, the location of future events cannot be identified exactly, because the areal unit used in assessing hazard is not always identical to the area specifically impacted by the hazard. For instance, the chance of occurrence of landslides within the high susceptibility zone can be calculated as the ratio of the landslide area to the high susceptible area, multiplied by the ratio of the area of the element of interest to the high susceptible area. The intensity of the hazard varies from place to place (e.g. flood depth, or landslide volume), and the exposure of the elements-at-risk varies.

Table 1: List of terms and definitions used in the GIS-based risk assessment

Term	Definition	Equations & explanation
Natural hazard (H)	A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity.	$\mathbf{P_T}$ is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario (H_s) with a given return period in an area; $\mathbf{P_L}$ is the locational or spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk
Elements-at-risk (E)	Population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area". Also referred to as "assets".	$\mathbf{E_s}$ is a specific type of elements-at-risk (e.g. masonry buildings of 2 floors)
Vulnerability (V)	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Can be subdivided in physical, social, economical, and environmental vulnerability.	**V** is the physical vulnerability, specified as the degrees of damage to E_S given the local intensity caused due to the occurrence of hazard scenario H_S It is expressed on a scale from 0 (no damage) to 1 (total loss)
Amount of elements-at-risk (A_E)	Quantification of the elements-at-risk either in numbers (of buildings, people etc), in monetary value (replacement costs etc), area or perception (importance of elements-at-risk).	**A** is the quantification of the specific type of element at risk evaluated (e.g. number of buildings)
Consequence (C)	The expected losses (of which the quantification type is determined by A_E) in a given area as a result of a given hazard scenario.	**C** is the "specific consequence", or expected losses of the specific hazard scenario which is the multiplication of $V_S * A_{ES}$
Specific risk (R_S)	The expected losses in a given area and period of time (e.g. annual) for a specific set of elements-at-risk as a consequence of a specific hazard scenario with a specific return period.	$R_S = H * V * A$ $R_S = H * C$ $R_S = P_T * P_L * V * A$
Total risk (R_T)	The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions in a given area and time period. It is calculated by first analyzing all specific risks. It is the integration of all specific consequences over all probabilities.	$R_T \approx \sum (R_T) = \sum(H_S * V * A)$ Or better: $R_T = \int (V_S * A_{ES})$ - For all hazard types - For all return periods - For all types of elements-at-risk. It is normally obtained by plotting consequences against probabilities, and constructing a risk curve. The area below the curve is the total risk.

The procedure is illustrated in figure 1, which shows an example of a floodplain with 3 different buildings (elements at risk) of two different construction types. These two types of buildings will have a different degree of vulnerability, given the same level of flooding.

Based on the analysis of historic flood damage for buildings with the same characteristics, flood vulnerability curves have been made, which reflect the relation between the flooddepth and the degree of damage. For this particular section of the flood plain a critical flood depth has been defined, based on inundation modeling as described in session 4. Given the historical discharge information, a flood with the level indicated in figure 6.2 is expected to occur on average every 10 years (the Return period is given as 10 years.). Therefore the annual probability is 0.1 (1/return period). The three elements at risk not only differ in type, but also in their economic value (Amount). For the flood risk estimation both the building value as well as the content value is used.

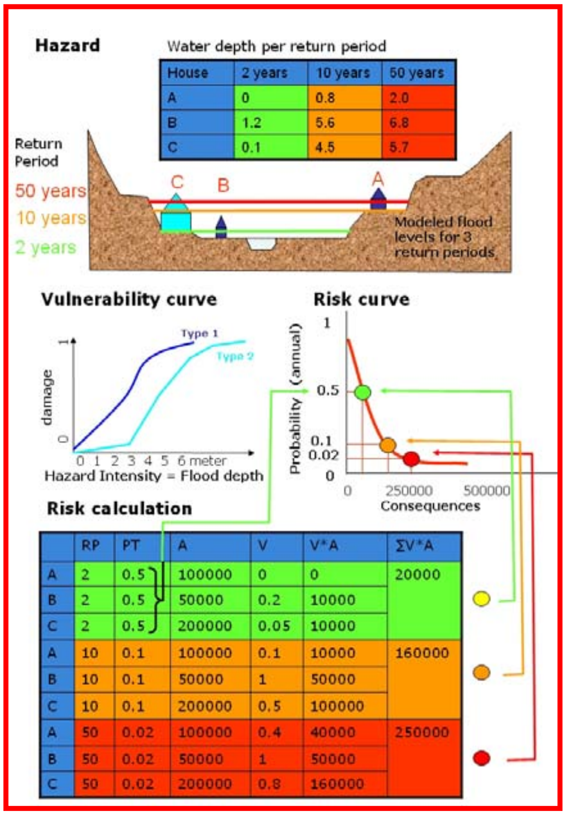


Figure 1 Simple example of a probabilistic risk assessment, resulting in the calculation of a risk

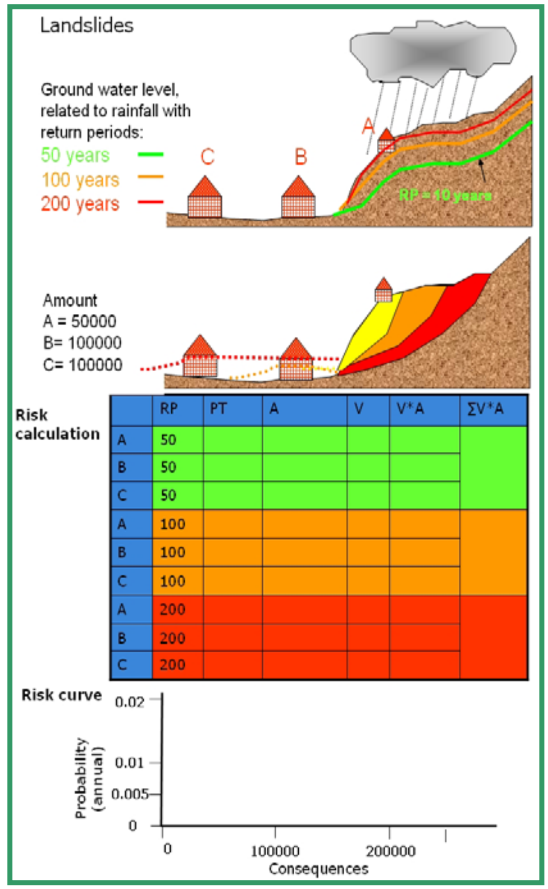


Figure 2: Example of quantitative landslide risk assessment.

Figure 2 presents the same concept but now for landslides. The hazard assessment starts with the modelling of groundwater depths, based on a slope hydrology model, where daily rainfall and the soil characteristics form the main sources of input. Based on the rainfall records and the modelling it is theoretically possible to estimate groundwater levels related to a particular return period.

Based on the groundwater modelling a second analysis is carried out using a physically based slope stability model to calculate the factor of safety for each particular return period. This results in three landslide scenarios, in which different volumes of landslides can be identified. The next step would be to carry out a run out analysis, to estimate the length of runout, the velocity and the depth of the landslide materials. These parameters would form the input in a vulnerability assessment.

- Calculate the specific risks for the individual risk scenarios for 50, 100 and 200 years, using the temporal probability (PT), the amount (A), and the vulnerability (V). In this case make an estimate of the expected degree of loss given the particular scenario. Calculate the consequences (V*A) and the sum of the consequences (∑V*A). Plot the Temporal probability against the total consequences and create the risk curve.

10.2 APPLICATION IN THE BARCELONNETTE CASE

As in many instances it is more difficult to do things in practice … We will see in this exercise the procedure that could be followed to try to make risk curves for multi-hazards in the Barcelonette region. But we will also see the problems that are involved, related to the lack of information.
The runout maps that you generated in the previous exercise are over large areas, and will overestimate the actual areas affected in the case of a major triggering event. If such an event occurs, there will be only a portion of these areas that will be actually affected. Therefore we need to incorporate an indication of the **spatial probability** of occurrence. The triggering event also has a certain **temporal probability** of occurrence that we could analyze based on meteorological data (e.g. precipitation, temperature changes) and establish thresholds in relation with the occurrence of past events. The temporal probability of these thresholds are then used in a frequency analysis, and the probability of these threshold levels are associated with the three events (Major,moderate and minor) that we have generated. To establish such threshold we need a substantial amount of historical landslide information. For the Barcelonette area this is limited unfortunately. Therefore we will estimate (guess) the temporal probability in this exercise.
Finally we also need to know the **magnitude probability**. In this case we will use the information derived from the FLOW-R programme as an indication of the magnitude of the event. The results are displayed in velocity, which we can convert to impact. This can be used as input in the vulnerability assessment.

So in this exercise we will have to estimate the following factors indicated in the table for the specific hazard type you have selected as a group.

Information required		Specific hazard type (snow avalanche, rockfall, debrisflow, Landslide)		
		Major event	Moderate event	Minor event
Rp	Return Period (years)	?	?	?
Pt	**Annual Probability (1/Rp)**	?	?	?
Nr	Number of occurrences per triggering event (-)	?	?	?
As	Total area affected by landslides in the triggering event (km^2)	?	?	?
Ar	Runout Area above a minimum threshold (km^2)	?	?	?
Ps	**Spatial probability**	?	?	?
A	**Amount of exposed elements at risk**	?	?	?
V	**Vulnerability of elements at risk**	?	?	?
Rs	**Specific Risk**	?	?	?

Given the short time available we will have to make a number of shortcuts. We will not deal with the aspect of V (vulnerability) and will simply take V=1. This means that exposed buildings are also destroyed. We will also not quantify A in terms of economic value, but use the number of buildings exposed as the measure of risk. In the flood risk exercise that we also have available these two aspects are dealt with a bit more (but still simple given the time available). We will start by calculating A = number of buildings exposed in each scenario (triggering event).

10.3 DISPLAYING ELEMENTS AT RISK DATA

In order to be able to make a risk assessment for Barcelonette we also need information on the elements at risk. Elements at risk : all objects and features that might be affected/ damaged/ destroyed/injured or killed by the hazardous phenol-mena.

In this exercise we limit ourselves to buildings, population and roads.

- Open the **Barcelonette_image**. Overlay the polgon map **Building_map** on the high resolution image by selecting: *Layers > Add Layer*. Zoom in to see the boundaries of the individual buildings. Double click on buildings to evaluate the information from the attribute table.
- Overlay also the polygon map **Landuse_2007** using only the boundaries. You can do this by selecting in the Display Options- Polygon Map the Box: *Boundaries Only*. Select for Boundary Color: Green and Boundary Width: **2** to make the lines thicker.
- Overlay the segment map **Road&Powerline**, use attribute TYPe, so that you can see which type of infrastructure there is.
- Overlay the map **Communes** and check the population information in the associated table.
- Close the map window
- Find out how many building there are in each of the communes. Also find out how many of these are residential buildings. Check the residential population per commune and find out the average number of persons per house. We will need this information later in the analysis.

10.4 CALCULATE THE ELEMENTS AT RISK EXPOSED

In order to be able to make an overlay of the hazard maps with the elements at risk we need to cross the two maps. The building map contains information on all the buildings in the study area, where each building has its own Unique Identifier. The runout maps show values in impact pressure. The combination of these two maps will result in many different combinations in the joint frequency table. The overlay is done for the three maps that you have obtained in the previous exercise for the runout of the process you selected: **Major_runout**, **moderate_runout**, **Minor_runout**.

Buildings affected

The Cross operation performs an overlay of two raster maps. Pixels on the same positions in both maps are compared. These combinations give an output cross map and a cross table. The cross table includes the combinations of input values, classes or IDs, the number of pixels that occur for each combination and the area for each combination

- Go to *operations, raster operations, cross* and select the **Building_Map** and the **Major_runout**. Call the output table **Major_Buildings**. Ignore the Undefs (undefined) values
- The cross table opens and you can see the large number of combinations between the building IDs and the values from the runout map

Now we need to know for each building what the maximum value is of the runout. You can do that aggregating the runout values for each building.

- In the cross table **Major_buildings**, select *column, aggregations* and select the column **Major_runout**, use the **Maximum** function and group by the **Building_map**. Click the option output table, and type **Building_map** and call the output column **Major_runout**.
- Open the table **Building_map** and check the result. Most of the buildings will not have a value for **Major_runout**, because they are not in the runout zone.
- We now want to know the number of buildings that are in the runout area. We can do this using the following formula:
- **Affected:=iff(isundef(Major_runout),0,1)**
- Make sure that in view, statistics pane is on. You can now read the number of buildings that are likely to be affected in this scenario, if all runout areas would be activated. Write down the number in the table below.
- Repeat the operation given above starting from the crossing, with the other two maps: **Moderate_runout** and **Minor_runout**. Fill in the table
- Evaluate if these values are reasonable.

	Major event	Minor event	Moderate event
Buildings affected			

Landuse affected

You can also do this for the other elements at risk. For instance for the landuse.

- Go to *operations, raster operations, cross* and select the map **Landuse** and the **Major_runout**. Call the output table **Major_Landuse**. Ignore the Undefs (undefined) values
- The cross table opens and you can see the large number of combinations between the landuse types and the values from the runout map.
- In the cross table **Major_landuse**, select *column, aggregations* and select the column **Area**, use the **Sum** function and group by the **Landuse**. Click the option output table, and type **Landuse** and call the output column **Major_affected_area**.
- Open the table **Landuse**. There you can see the values for the areas affected in the various landuse classes. Calculate them in km^2 using the formula:

  Affected:=Major_affected_area/1000000

☞ Write down the numbers in the table below.

☞ Repeat the operation given above starting from the crossing, with the other two maps: **Moderate_runout** and **Minor_runout**. Fill in the table. Evaluate if these values are reasonable.

Area affected	Major event	Minor event	Moderate event
Forest			
Arable land			
Pastures			
Urban fabric			

Transportation affected

Also it is possible to calculate the length of roads and powerline that are affected by the particular process .

- Go to *operations, raster operations, cross* and select the map **Road&Powerlines** and the **Major_runout**. Call the output table **Major_transport**. Ignore the Undefs (undefined) values
- In the cross table **Major_transport**, select *column, aggregations* and select the column **Npix**, use the **Sum** function and group by the **Road&Powerline**. Click the option output table, and type **Road&Powerline** and call the output column **Major_affected_npix**.
- Open the table **Road&Powerline**. There you can see the length of the individual sections. We will calculate the percentage of affected area values for the areas affected in the various landuse classes. Calculate them in km2 using the formula:

  Affected:=Length*(Major_affected_npix/Npix_total)
- In the table **Road&Powerline**, select *column, aggregations* and select the column **Affected**, use the **Sum** function and group by the **Type**. Click the option output table, and type **Transport** and call the output column **Affected_length**.
- Open the table **Transport**. Write down the affected length of the various types in the table below.
- Repeat the operation given above starting from the crossing, with the other two maps: **Moderate_runout** and **Minor_runout**. Fill in the table. Evaluate if these values are reasonable.

Length affected (km)	Major event	Minor event	Moderate event
Main road			
Secondary road			
Unpaved road			
Ski_chair_lift			
Skilift			
Electric powerline			

The other groups that have worked on the other hazard types also have calculated the elements at risk that are exposed in their Major, moderate and minor triggering events. It would be good at this point to exchange this information, and compare the number of buildings exposed, the area of the landuse affected, and the length of the infrastructure exposed for the different hazard types.

10.5 ESTIMATE THE SPATIAL AND TEMPORAL PROBABILITY OF THE EVENT

The three maps that you have generated in the previous exercise (**Major_runout**, **moderate_runout**, **Minor_runout)** indicate the areas that might be affected by the runout of the mass movement type that you selected (rockfall, debrisflows, snow avalanches and landslides). However, during one triggering event it is very unlikely that all the areas would be affected at the same time. Of the modeled area only a portion will be affected. It is not possible to know this portion beforehand. What you can say is that during a major triggering event the areas that are also affected during moderate and minor triggering events have a higher probability.

What we will assume is that if we know the area affected by mass movements during a past triggering event, we can use the ratio between this area and the total area of the runout modeled area as an indication of the spatial probability. The spatial probability indicates then the probability that a particular location (e.g. an element at risk) could be affected.

$$\text{Spatial probability} = \frac{\text{Area affected in a past triggering event}}{\text{Area modeled to be affected by the same triggering event}}$$

We should therefore get this type of information from past events, and inventories that also show when the various mass movements have occurred. We have this type of information only to a certain extend. So let us look at the inventories of mass movements. The table below summarizes the inventories:

	Spatial occurrence	Temporal information	Magnitude
Snow avalanches	**Avalanche_ID_field** **Avalanche_ID_photo** Known avalanches	Attribute tables have dates but not reliable	• Simple estimation of impact pressure from FLOW-R • Frequency-size distribution of events
Rockfall	Map: **Rockfall**: Only rockfall accumulation areas.	Not available	Simple estimation of impact pressure from FLOW-R
Debrisflow	Not available. Only modeled runout	Debrisflow_dates: for 53 events	Simple estimation of impact pressure from FLOW-R
Landslides	Landslides_2007: inventory is not complete	Landslide_dates: for 53 events	• Simple estimation of impact pressure from FLOW-R • Frequency-size distribution of events
Flood	No flood inventory. Only model results: Flood 100 y, Flood 150 y, Flood 250 y, Flood 500 y	See return periods of modeled events	Flood depth for each return period

As you can see from the above table, there are quite some problems in estimation the risk due to the individual hazards as in almost all cases one of the components is missing. So we will have to make some expert judgements (or guesses).

You should select one of the hazard types. Preferably the one on which you have worked before in the run-out analysis, and try to get estimates of the spatial and temporal probabilities. In the part below only some hints are given because it is difficult to outline in detail.

In the following sections we give you some hints to evaluate the temporal probability of the three triggering events that you have analyzed in the runout modeling part.

10.6 ESTIMATING THE TEMPORAL PROBABILITY OF EVENTS

For both landslides and debris flows we have a table that contains a number of known landslide and debrisflow events, together with their dates of occurrence and the rainfall information. These are stored in the tables **Landslide_dates** and **Debrisflow_dates**. They contain daily, monthly, yearly rainfall and some antecedent rainfall amounts.

- Open the table **Landslide_dates** or **Debris_flow dates** and check the contents.
- Make a plot of the daily rainfall (PDay) against different antecedent rainfall amounts in order to see if there is a possibility to plot some rainfall thresholds, that would separate landslide days from non-landslide days. Can you find any relation?
- We can also calculate the number of events per year. Select *column, aggregations* and select the column **Yearcl**, use the **Count** function and group by the **Yearcl**. Click the option output table, and type **Year** and call the output column **Nr_DF** or **Nr_LS** (depending whether you work with debris flows or landslides).
- Open the table Year, and see if there are years with more debrisflow or landslide events. Ideally you would then be able to indicate mean intervals between successive triggering events, and use the Poisson analysis to get an indication of the return period.

You can estimate the mean landslide recurrence interval (μ) by dividing the period of analysis (60 years) by the number of predicted landslide event-years (major, moderate and minor). You then use the estimated μ to calculate the exceedance probability of landslide events by using the Poisson distribution model. The basic assumption of these models is that the occurrence of landslide event within any given period is random. In the Poisson distribution model, exceedance probability or probability of experiencing one or more landslide events during period ‘t’ can be estimated by the following equation:

$$P[N_L(t) \geq 1] = 1 - P[N_L(t) = 0] = 1 - e^{-\lambda t} = 1 - e^{-t/\mu}$$

where $P[N_L(t) \geq 1]$ is exceedance probability or probability of occurrence of one or more landslide event in period t and λ is the reciprocal of the mean recurrence interval (μ), that is, $\lambda = \frac{1}{\mu}$.

For snow avalanches we also have some information on occurrence dates in the table

Avalanche_ID_field.

- Open the table **Avalanche_ID_field** and check the contents
- We can also calculate the number of events per year. Select *column, aggregations* and select the column **Yearcl**, use the **Count** function and group by the **Yearcl**. Click the option output table, and type **Year** and call the output column **Nr_Ava**.
- Open the table **Year**, and see if there are years with more debrisflow or landslide events. Ideally you would then be able to indicate mean intervals between successive triggering events, and use the Poisson analysis to get an indication of the return period.

For rockfalls we do not have any date of occurrence. Based on the scarce information that we have on the occurrence of historical events, you will have to make an estimate (guess) now of the return periods, and annual probability of the three triggering events for the hazard types. Write the values in the table below.

Hazard type	Triggering event					
	Major		Moderate		Minor	
	Return Period	Annual Probability	Return Period	Annual Probability	Return Period	Annual Probability
Snow avalanches						
Rockfall						
Debrisflows						
Landslides						

10.7 ESTIMATING THE SPATIAL PROBABILITY OF EVENTS

The spatial probability gives an indication of the probability that if a triggering event occurs (be it Major, Moderate or Minor), and an element at risk is located in the modeled runout area, what will be the probability that this particular element at risk would be hit. Since the runout maps cover quite a large area, it is not to be expected that all the modeled areas will be affected. Also by looking at the past events, we can see how many individual mass movements have occurred during a triggering event, and what their size was. If we can estimate the total area that has been covered during historic events of the particular triggering magnitude class, we then divide the modeled area of runout by this area to give an indication of the probability that an individually exposed element at risk would be hit. So we need to look at the inventories and estimate their size distribution. We do that through histograms.
Let us look how we could do that for landslides, snow avalanches and rockfalls. For debrisflows we don't have an inventory map, so that will be difficult. For the others it is also difficult because we have complete inventories without good separation of triggering events.

- Open the table **Year** and make a graph in which you display the number of landslides, debrisflows or snow avalanches per year. Find out the number of events that is occurring in three classes: major events, moderate events and minor events. Write these numbers in the table below.

- Then look at the average size of landslides, rockfalls or snow avalanches, by generating a histogram of the polygon maps **Landslides_2007**, **Rockfall** or **Avalanche_ID_field**. From this histogram you can then calculate the average size of the features and write them also in the table below.
- For debrisflows we don't have an inventory map, so you will have to make a direct estimation of the size of the area affected in a single event.

Hazard type	Triggering event					
	Major		Moderate		Minor	
	Number of events	Average size	Number of events	Average Size	Numer of events	Average size
Snow avalanches						
Rockfall						
Debrisflows						
Landslides						

We then need to know also the total area that is modeled in the runout scenarios for the major, moderate and minor events.

- Calculate the histograms for the maps Major_runout, Moderate_runout and Minor_runout and obtain the total area affected for each event. Write these in the table below.
- Then look at the average size of landslides, rockfalls or snow avalanches, by generating a histogram of the polygon maps **Landslides_2007**, **Rockfall** or **Avalanche_ID_field**. From this histogram you can then calculate the average size of the features and write them also in the table below.
- For debrisflows we don't have an inventory map, so you will have to make a direct estimation of the size of the area affected in a single event.
-

Hazard type	Triggering event		
	Major	Moderate	Minor
	Area affected =	Area affected =	Area affected =
	Spatial probability	Spatial probability	Spatial probability
Snow avalanches			
Rockfall			
Debrisflows			
Landslides			

10.8 ESTIMATE THE SPECIFIC RISK FOR THE THREE EVENTS

Now that we have all the information to make the risk assessment, you should write down the values for the different components of the risk equation in the table below / or better in an Excel sheet.

Information required		Specific hazard type :		
		Major event	Moderate event	Minor event
Rp	Return Period (years)			
Pt	**Annual Probability (1/Rp)**			
Ps	**Spatial probability**			
A	**Amount of exposed elements at risk**			
V	**Vulnerability of elements at risk**	**1**	**1**	**1**
L	**Losses = Ps * A *V**			

- Calculate the individual components of the loss equation in an Excel sheet.
- Plot the values of the Losses (L) against the Annual probability for the three events.
- Generate a risk curve by connecting the 3 points in the curve.
- Obtain the risk curve from other groups on different hazard types, and compare the results: which of the hazards in the Barcelonette area poses the largest problem?

10.9 RESULTS

Buildings affected

Buildings affected	Major event	Moderate event	Minor event
Debrisflows	496	171	0
Landslides	49	1	0
Rockfall	240	13	0
Snow avalanches	55	0	0

Land use affected

Area affected	Major event	Moderate event	Minor event
Forest	24	4.4	3.1
Arable land	2.0	0.7	0.05
Pastures	12.1	4.4	0.45
Urban fabric	0.58	0.11	0.02

Transportation affected

Length affected (km)	Major event	Moderate event	Minor event
Main road	3.71	1.29	0.18
Secondary road	55.27	18.24	2.21
Unpaved road	150.41	49.01	2.91
Ski_chair_lift	0.12	0	0
Skilift	0.23	0	0
Electric powerline	2.33	0	0

Temporal probability (guestimate):

Hazard type	Triggering event					
	Major		Moderate		Minor	
	Return Period	Annual Probability	Return Period	Annual Probability	Return Period	Annual Probability
Snow avalanches	100	0.01	50	0.02	10	0.1
Rockfall	500	0.002	200	0.005	50	0.02
Debrisflows	100	0.01	50	0.02	10	0.1
Landslides	100	0.01	50	0.02	25	0.04

Number of events and area (partly guestimate, partly from histogram):

Hazard type	Triggering event					
	Major		Moderate		Minor	
	Number of events	Average size	Number of events	Average Size	Numer of events	Average size
Snow avalanches	20	40000	10	20000	5	10000
Rockfall	7	10000	5	5000	2	2500
Debrisflows	15	40000	10	20000	5	10000
Landslides	50	10000	20	5000	5	2500

Area modelled (from histogram. We could use a threshold to reduce):

Hazard type	Triggering event		
	Major	Moderate	Minor
	Area affected	Area affected	Area affected
Snow avalanches	26189000	12293000	4377000
Rockfall	42264000	23125000	9672000
Debrisflows	48970000	28532000	7295000
Landslides	30195000	11763000	5006000

Number of events and area (partly guestimate, partly from histogram):

Hazard type	Triggering event					
	Major		Moderate		Minor	
	Number of events	Average size	Number of events	Average Size	Numer of events	Average size
Snow avalanches	20	40000	10	20000	5	10000
Rockfall	7	10000	5	5000	2	2500
Debrisflows	15	40000	10	20000	5	10000
Landslides	50	10000	20	5000	5	2500

Spatial probability (guestimate):

Hazard type	Triggering event		
	Major	Moderate	Minor
	Spatial probability	Spatial Probability	Spatial probability
Snow avalanches	0.030547	0.016269	0.011423
Rockfall	0.001656	0.001081	0.000517
Debrisflows	0.012252	0.00701	0.006854
Landslides	0.016559	0.008501	0.002497

Final resulting risk

Information required		Specific hazard type :			Specific hazard type :			Specific hazard type :			Specific hazard type :		
		Debris flows			**Landslides**			**Rockfall**			**Avalanches**		
		Major event	Moderate event	Minor event	Major event	Moderate event	Minor event	Major event	Moderate event	Minor event	Major event	Moderate event	Minor event
Pt	**Annual Probability (1/Rp)**	0.01	0.02	0.1	0.01	0.02	0.04	0.002	0.005	0.02	0.01	0.02	0.1
Ps	**Spatial probability**	0.01	0.007	0.006	0.01	0.008	0.002	0.002	0.001	0.0005	0.03	0.02	0.01
A	**Amount of exposed elements at risk**	496	171	1	49	1	0	240	13	0	55	0	0
V	**Vulnerability of elements at risk**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
L	**Losses = A *V**	496	171	1	49	1	0	240	13	0	55	0	0
L	**Losses = Ps * A *V**	4.96	1.197	0.006	0.49	0.008	0	0.48	0.013	0	1.65	0	0
L	**Losses = Ps * A *V *20000 (average costs)**	992000	239400	1200	98000	1600	0	96000	2600	0	330000	0	0

11 QUALITATIVE MULTI-HAZARD RISK ASSESSMENT USING SPATIAL MULTI CRITERIA EVALUATION: THE CASE STUDY OF BARCELONNETTE, FRANCE

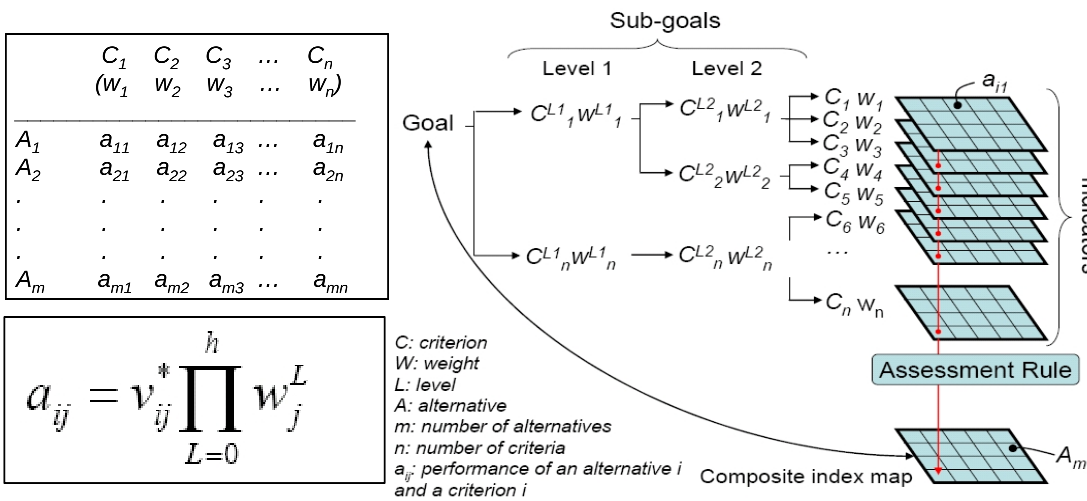


Figure 1. Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

Expected time: 4 hours

Data: **Exercise_Barcelonnette_SMCE.zip** Size : 3.6 Mb

Objectives: After this exercise you will be able to generate:

- A hazard index, which combines the source maps, runout maps, and inventories for the various hazard types
- A vulnerability index that combines the various elements at risk
- Both are standardized and weighted.
- The combination of the hazard index and the4 vulnerability index map is used as a tool for spatial planning and risk management.
- All procedures are based on Spatial Multi Criteria Evaluation

11.1 INTRODUCTION

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 RiskCity 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.
From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in Figure 6.8. 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).

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:
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.

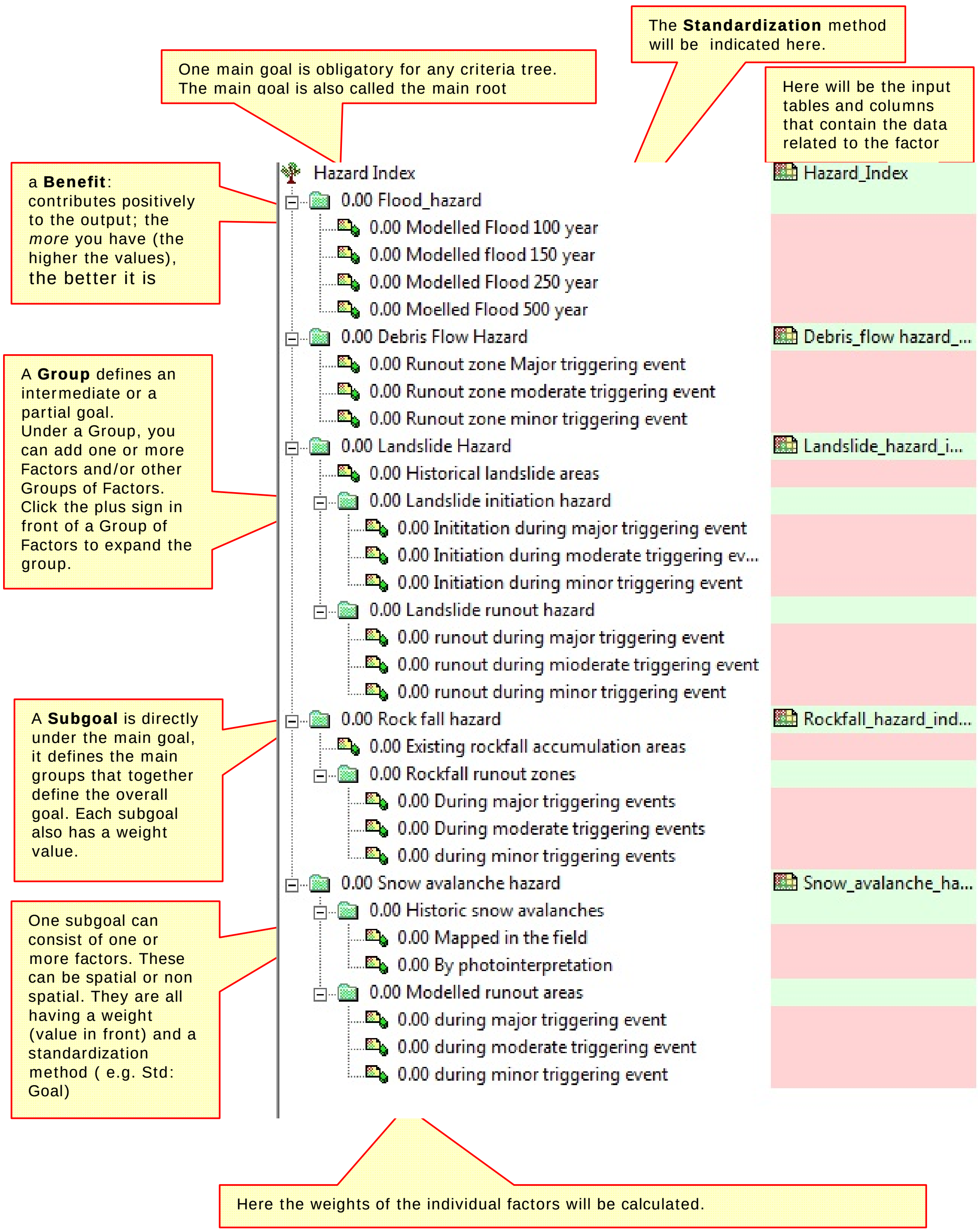
General steps in the process are:

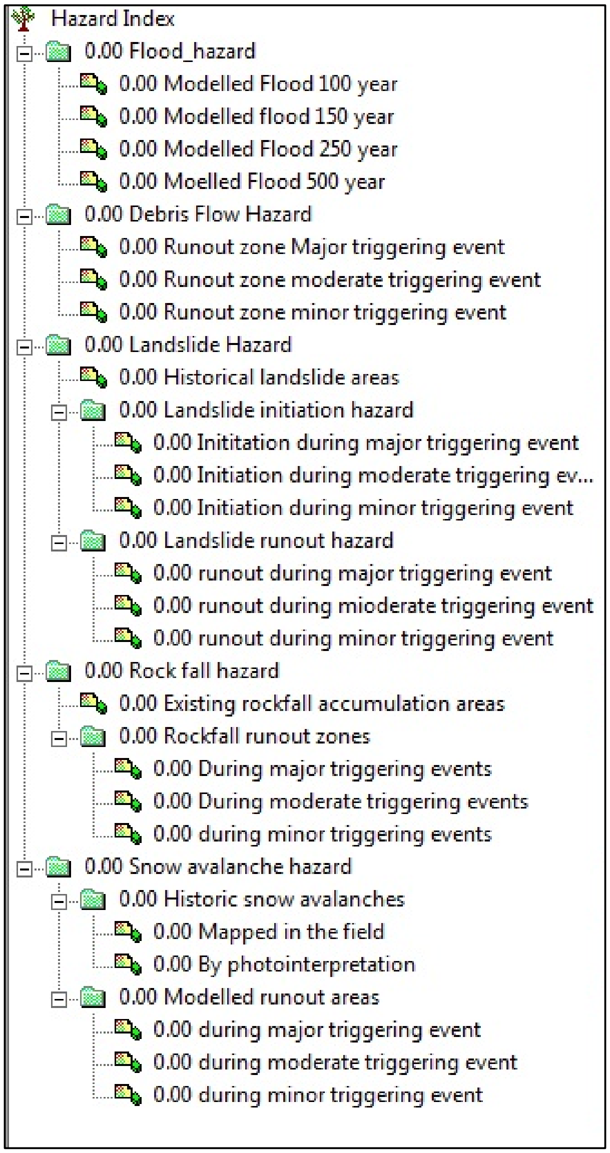
1. **Definition of the problem**. Structuring of the problem into a criteria tree, with several branches or groups, and a number of factors and/or constraints.
2. **Standardization of the factors**. All factors may be in different format (nominal, ordinal, interval etc.) and should be normalized to a range of 0-1. SMCE has some very handy tools for that especially for value data, making use of different transformation graphs.
3. **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.
4. **Weighting of the groups**, in order to come to an overall weight value.
5. **Classification** of the results.

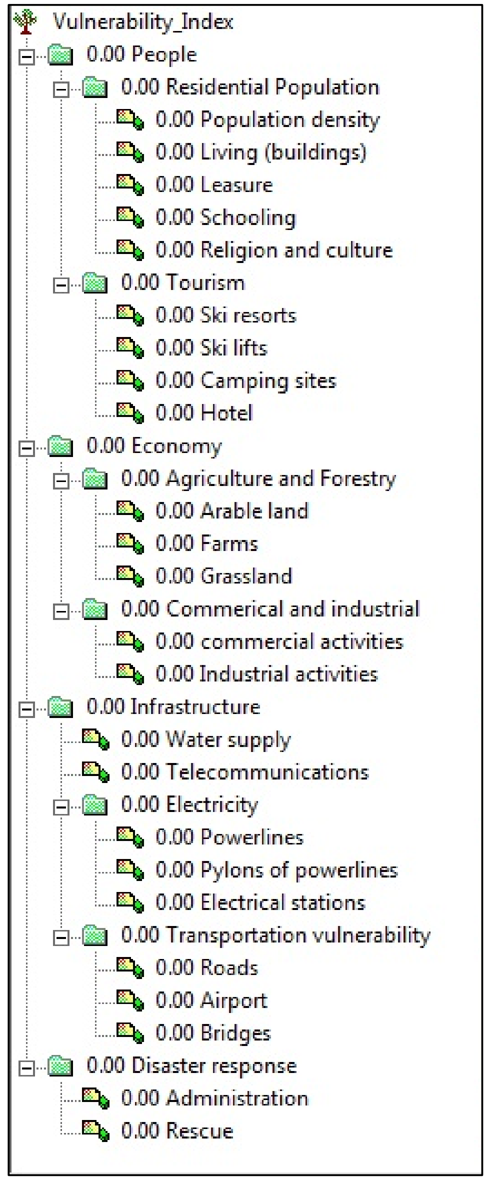
A criteria tree may contain:

- **Main goal**: One main goal is obligatory for any criteria tree. The main goal is also called the main root.
- **Constraint:** Constraints are binding criteria so no compensation is allowed. Areas in an input map (added as a constraint) that do not satisfy a constraint condition, will obtain a composite index value of 0, no matter how well these areas perform in any other criterion (factor). Constraints can only appear directly under the main goal.
- **Factor**: Factors allow for compensation. Poor performance in one criterion can be compensated by good performance in another criterion. Factors may appear directly under the main goal or under a group of factors (sub-goal), or even under a sub-sub-goal (objective**). A factor can be a benefit (the higher the value, the better), or a cost (the higher the value, the worse).**
- **Group of Factors**: A Group defines an intermediate or a partial goal. Under a Group, you can add one or more Factors and/or other Groups of Factors. Click the plus sign in front of a Group of Factors to expand the group.

Figure 2 gives an overview of the final criteria tree for the hazard index that could be used for this exercise.
Figure 3 gives an examples of the possible criteria trees for the hazard index and the vulnerability index that could be used for this exercise. You can of course deviate from this set-up and design your own criteria tree in a different way.


The **Standardization** method will be indicated here.
One main goal is obligatory for any criteria tree. The main goal is also called the main root
Here will be the input tables and columns that contain the data related to the factor
a **Benefit**: contributes positively to the output; the *more* you have (the higher the values), the better it is
A **Group** defines an intermediate or a partial goal. Under a Group, you can add one or more Factors and/or other Groups of Factors. Click the plus sign in front of a Group of Factors to expand the group.
A **Subgoal** is directly under the main goal, it defines the main groups that together define the overall goal. Each subgoal also has a weight value.
One subgoal can consist of one or more factors. These can be spatial or non spatial. They are all having a weight (value in front) and a standardization method (e.g. Std: Goal)
Hazard Index
0.00 Flood_hazard
0.00 Modelled Flood 100 year
0.00 Modelled flood 150 year
0.00 Modelled Flood 250 year
0.00 Moelled Flood 500 year
0.00 Debris Flow Hazard
0.00 Runout zone Major triggering event
0.00 Runout zone moderate triggering event
0.00 Runout zone minor triggering event
0.00 Landslide Hazard
0.00 Historical landslide areas
0.00 Landslide initiation hazard
0.00 Inititation during major triggering event
0.00 Initiation during moderate triggering ev...
0.00 Initiation during minor triggering event
0.00 Landslide runout hazard
0.00 runout during major triggering event
0.00 runout during mioderate triggering event
0.00 runout during minor triggering event
0.00 Rock fall hazard
0.00 Existing rockfall accumulation areas
0.00 Rockfall runout zones
0.00 During major triggering events
0.00 During moderate triggering events
0.00 during minor triggering events
0.00 Snow avalanche hazard
0.00 Historic snow avalanches
0.00 Mapped in the field
0.00 By photointerpretation
0.00 Modelled runout areas
0.00 during major triggering event
0.00 during moderate triggering event
0.00 during minor triggering event
Hazard_Index
Debris_flow hazard_...
Landslide_hazard_i...
Rockfall_hazard_ind...
Snow_avalanche_ha...
Here the weights of the individual factors will be calculated.





11.2 CREATING THE CRITERIA TREE FOR THE HAZARD INDEX / VULNERABILITY INDEX

In this step we will generate in the ILWIS Spatial Multi Criteria Evaluation (SMCE) software tool, a problem tree that will be used to calculate the hazard index. If you decided to make the vulnerability index, it works more or less the same way. We have used the hazard index as example, but you can also work on the vulnerability index.
Below we will take you through the procedure. Later on you can do it yourself for the other groups.

11.3 PROBLEM DEFINITION AND CREATION OF THE CRITERIA TREE

Which criteria to use, and how to order them? This is often one of the most difficult parts of the procedure.
The criteria tree is composed of the following criteria:

- **Constraints**: these criteria are used to mask out the area where the goal can not be reached. In this case, where there is no social vulnerability, because there are no people living.
- **Factors**: those are the criteria that contribute in different way to the goal (social vulnerability score in this case). We can group these into several sub-goals or groups.

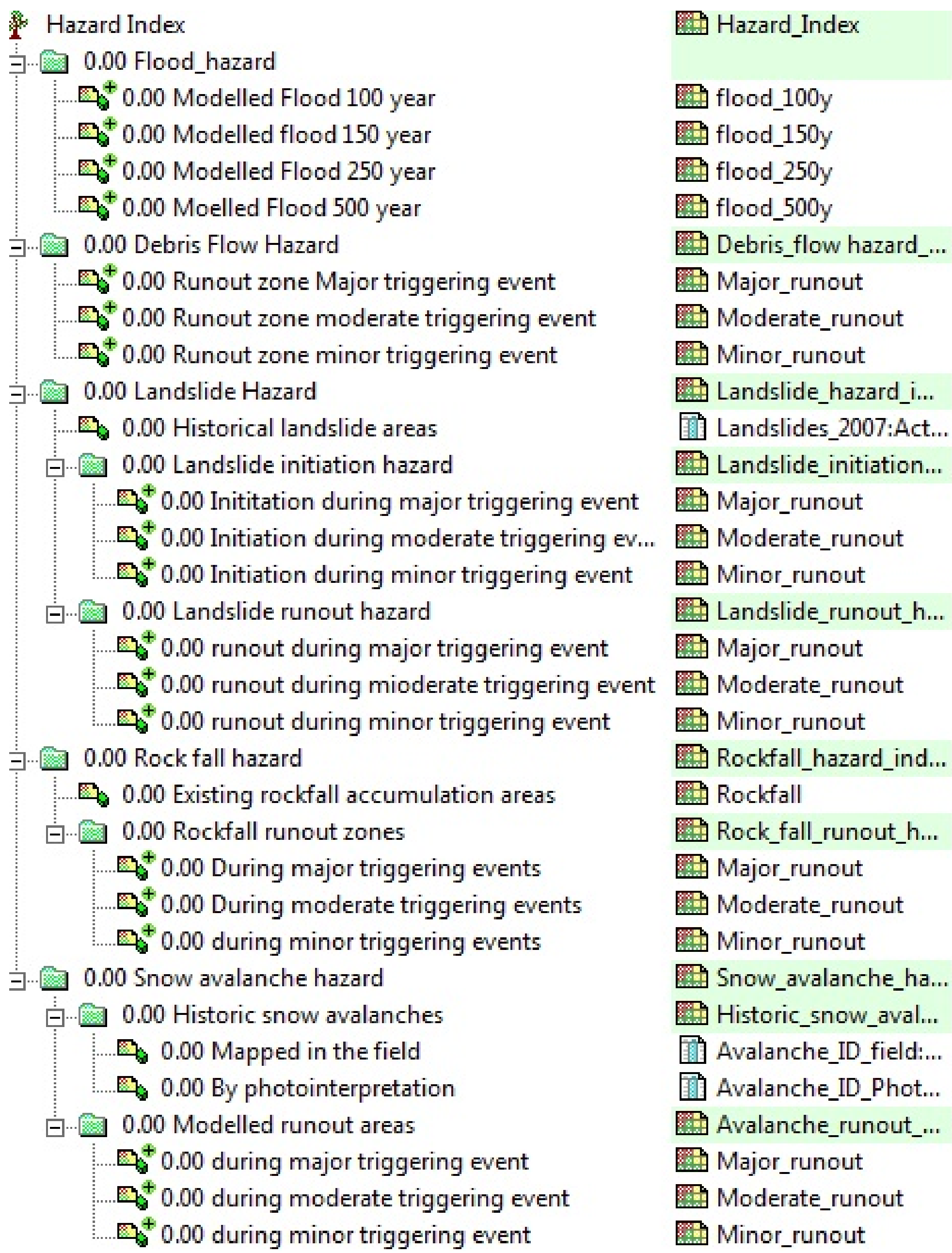
- Select *Operations / Raster Operations / Spatial Multi Criteria* Evaluation. Select the option Problem Analysis. An empty problem tree is opened (or select Spatial Multi-Criteria Evaluation in the Operations List)
- Change the goal (right click select Edit)to: **Hazard_Index**, and the name of the output map (in the right side) to **Hazard_Index**.
- Click on **Hazard_Index** and click on the insert group icon or Right click on it and select *Insert group*. Add the groups: **Flood_hazard**, **Debris_flow_hazard**, **Landslide_hazard**, **Rockfall_hazard** and **Snow_avalanche_hazard**.
- Include the various spatial factors and groups for the individual criteria, as indicated above in the example by right-clicking on the individual criteria and inserting the spatial factors or click the insert spatial factor icon .
- You can of course deviate from the example if you think you should do it differently
- Note: all parts indicated in red should be completed before you can make the output map.

Next you will have to assign the spatial data that is relevant for each of the criteria that you have defined. These are mostly coming from maps or from tables associated to maps

- Important: SMCE works only with raster maps, not with vector maps. You have to rasterize these first. The Rastermaps should all have the same georeference (the file defining the boundaries of the raster map and the pixelsize).
- Double click on the red area next to **Modelled_flood_100_year**. Select the map **Flood_100y**.
- Find also the relevant spatial information for the other criteria
- Save the criteria tree as **Hazard_Index**
- Adding output maps : Double click on the green area next to “ Flood hazard” and fill in **Flood_hazard**. Press enter

- Do the same for the other main subgoals and create the tree that looks like the one on the next page

Once you have done this the decision tree might look like the one below. All the input and output maps have been defined



11.4 STANDARDIZATION OF THE FACTORS.

Some of the factors used in the hazard index assessment are of the "value" type, and some will be classes (e.g. the landslide information) which are stored as attributes in an attribute table linked to one map.

Next we need to standardize these different values, and normalize them to values ranging from 0 to 1.

Standardization and the design of value functions is a crucial part of the SMCE. Different standardization methods express different utility of input values. When standardizing, depending on the type of input map, a dialog box will appear in which you can choose the "value function" by which the map or column values are converted to values between 0 and 1. Standardization is part of the Multi Criteria Analysis mode in ILWIS-SMCE.

- In the SMCE window, change the Mode from "*Problem Definition*" to "*Multi Criteria Analysis*". The entire left part of the tree will become red now, indicating that you still need to fill these in. Now you can start standardization.
- Double click on the red area indicating **0.00 Modelled_Flood 100 year**. Now a window opens in which a graph is shown fitting the data range of values for this factor over the range of 0-1.

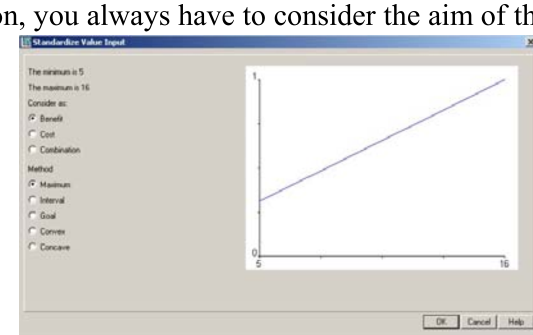
How to standardize?

You have to define yourself the ranges between you standardize. Consider for each factor: how much should the value be in order to consider it very vulnerable? For instance: how large should the percentage elderly people per mapping unit be to give it a 1 value (highly vulnerable). These threshold values are often defined in a group decision making process:

- **Maximum**: The input values are divided by the maximum value of the map;
- **Interval**: Linear function with the maximum and minimum values of the map;
- **Goal**: Linear function with specified maximum and minimum values;
- **Piecewise linear**: Linear function with two breaking points located between the extremes
- **Convex**: Convex function with one user defined value to re-shape the curve;
- **Concave**: Concave function with one user defined value to re-shape the curve;
- **U-Shape**: U-shape curve with one user defined value to stretch or shrink the curve GaussianBell-shape curve with one user defined value to stretch or shrink the curve.

You have the option to select several ways of scaling the values between 0 and 1. The figure below shows the standardization window, and the various options.

When selecting the boundaries for standardization, you always have to consider the aim of the weighting and standardization procedure (in this case social vulnerability), and how this particular variable is related to that. In this case: the higher the percentage of children in an area, the higher the vulnerability of the population. In that case you can use a simple straight line, between 0 and the maximum value. In other cases there will be a maximum value above



which you will always find it high. E.g. for the estimation of the population losses, you could say that anything above 20 is high, and should be 1. In that case you select the Goal option, and you can adjust the values manually.

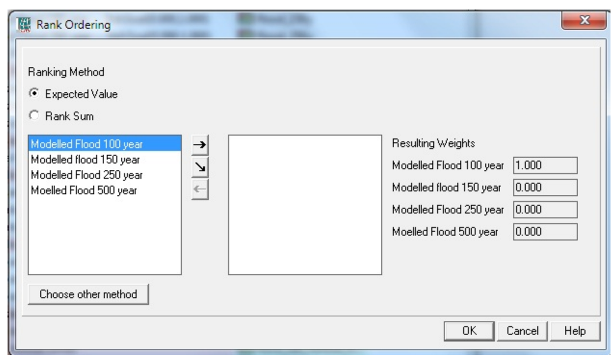
- Select the goal option and change the minimum X and the maximum based on your opinion of the importance of the given water height for the overall vulnerability. For instance you could standardize between 0 and 2 meters, for all the flood maps.
- Standardize in the same way the other variables.

After standardizing all factors, your criteria tree will have only red bars in the combination of the factors. The red bars are showing the places where still you need to indicate weights.

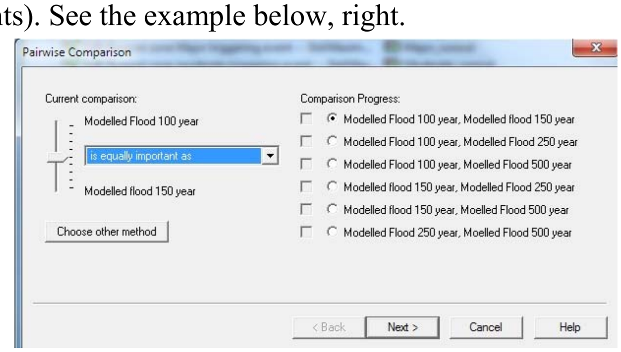
- To see the result of the standardization: Right click on a name and select *Show standardized*. A map opens that contains the standardized values.
- Open *PixelInformation* and add the map you just created and also the map **t**. Compare the original values to the standardized values.

11.5 DETERMINING THE WEIGHTS AMONG FACTORS

The third step in the procedure is to define the weights between the various factors. This can be between the factors in the same group (e.g. the two factors "Modelled Flood 100 year" and "Modelled Flood 500 year" in the group "Flood hazard"), or the weights among the groups (e.g. "Flood hazard" versus "Debris flow hazard"). For the determination of weights SMCE use 3 different methods:



- **Direct weights** (you indicate the weights directly in a table),
- **Pairwise comparison** (you compare the factors in pairs, and based on the consistency of your selection and relative importance, quantitative values are given to the factors), See the example below left and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights). See the example below, right.



Weights

Weights are always numbers between 0 and 1. Weights cannot be negative. For the factors within a group, the sum of the weights of the factors equals 1. When a group only has one child, this child automatically obtains weight 1.

Constraints are not considered during weighing.

- Right-click the red indicated factor group "***Flood Hazard***", and select Weight. Select the option: *Pairwise*
- Determine whether for the determination of flood hazard, the modeled flood in 100 year is more important than the modeled flood in 250 year, or equal, or less. Discuss this with your neighbors / group members.
- Double-click on the **Flood_Hazard** map name and generate the map. View the result.
- Generate also the weight for the other groups.

11.6 DETERMINING THE WEIGHTS AMONG GROUPS

The fourth step in the procedure is to define the weights between among the groups (e.g. "Flood HAzard" versus "Debris flow hazard"). There are five groups in this example. Also here pair wise method could be used, but you might also try out another one.

- Right-click the red indicated upper line *"Hazard Index"*, and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance. Discuss this with your neighbors / group members.

Now all the parameters are given and it is time to calculate the output map.

- Right-click the map icon "**Hazard_Index**", and select Generate selected item
- Also evaluate the individual hazard map for **Flood_hazard**, **Debrisflow_Hazard** etc.
- Display the result map. Use *PixelInfo* to compare the resulting map with the input maps. You can adjust the standardization, and weights if you would like to make adjustments
- Question: What can you conclude from the pattern of different hazards?

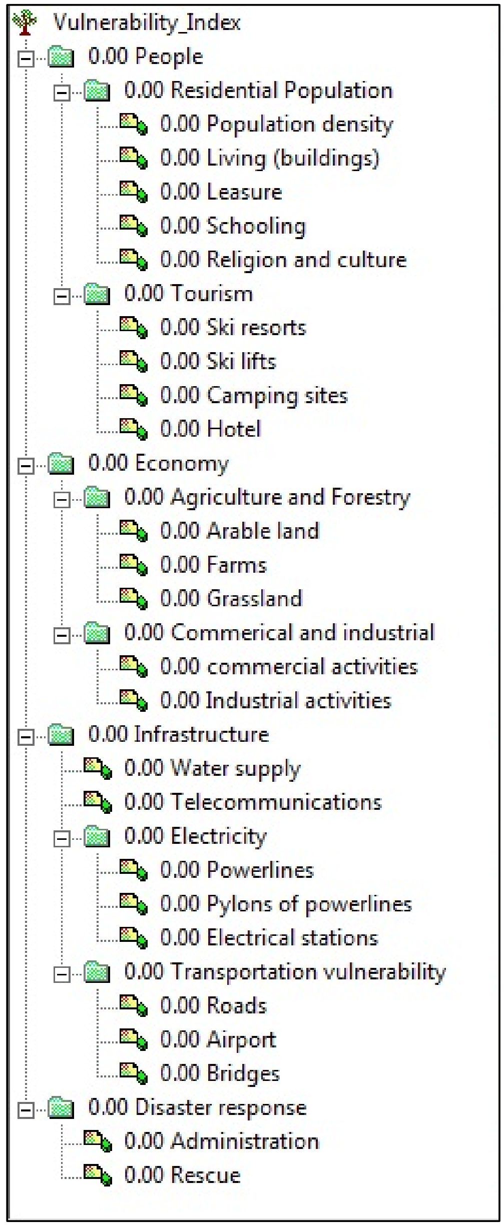
You can also classify the output map, or the intermediate hazard maps in a few classes. For that we will use again a Class/Group domain. Remember that all the result maps have values between 0 and 1.

- Classify the output map **Hazard_Index** in three classes (use Operations, Image Processing, Slicing). Name the output: **Hazard_Class**
- You can also classify the individual hazard maps for flood, debris flows, snow avalanches, rockfall and landslides.
- Critically evaluate the result.

11.7 CREATING THE CRITERIA TREE FOR VULNERABILITY INDEX

You can also generate the criteria tree for the vulnerability index, or you can exchange the information with another group that did the vulnerability hazard.

- Generate the criteria tree for **the Vulnerability_Index**.
- In this exercise we have not written out in detail how to generate this vulnerability criteria tree and which indicators to use. The tree that is shown on this page only gives a suggestions. The indicators required for this particulat set-up might not be all available. Check first the available data and analysis wich indicators you can use.
- The tree shown here also doesn not have the weights yet. You will have to define this yourself.
- Do not use Windows explorer to copy/delete or rename individual files. Use the options in ILWIS itself (under Edit) to copy or delete files. Due to the object oriented approach of ILWIS, one file is associated with several other files that are needed for displaying it. When you copy files with Windows explorer you will forget which files are linked, and then you run the risk that the file will not open anymore. So always copy files by clicking on it in the data catalog and then select from the menu: Edit, Copy Object To
- Classify the **Vulnerability_Index** map, and also the intermediate maps (**People, Economy, Infrastructure, Disaster Response**) using the Class/Group domain **Vulnerability_Class**.



11.8 COMBINING THE HAZARD AND VULNERABILITY MAPS

Once the various hazard maps (including the overall Hazard_Index and Hazard_Class maps) and the various vulnerability maps (including the Vulnerability_Class map) have been generated, you can now use them in many different ways. We will focus on the use of these maps in the last exercise. Here we will only make a very simple overall risk map to conclude. We do this using a two-dimensional table, called Qualitative_risk.

The table looks like this:

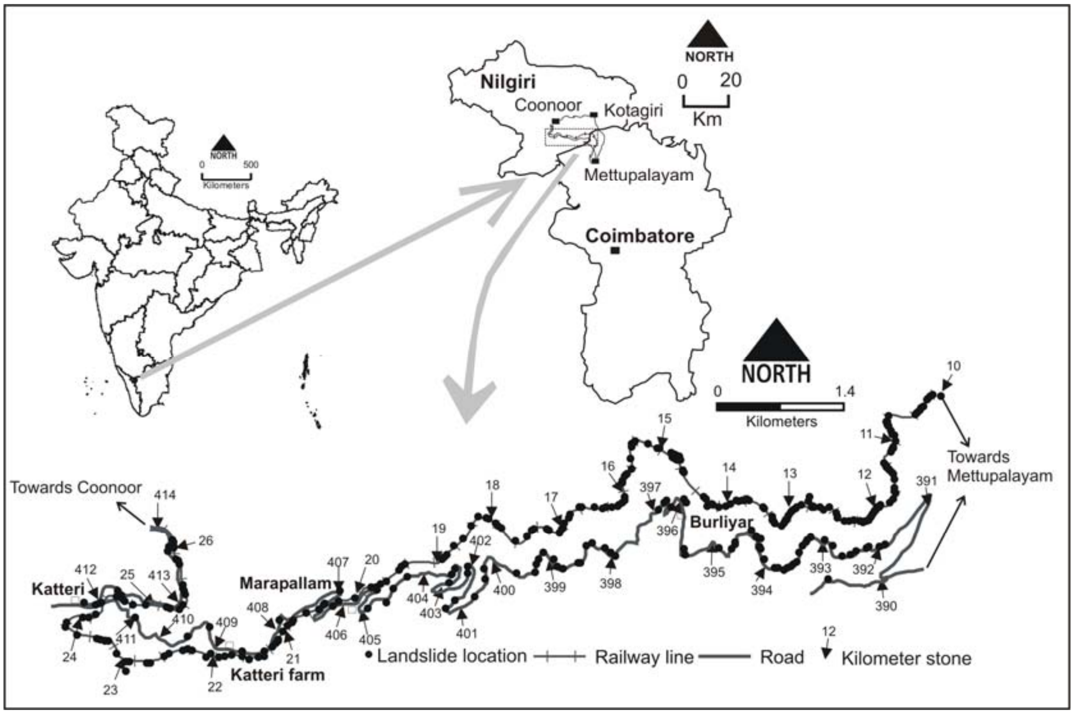
		Vulnerability		
		High	Moderate	Low
Hazard	High	High	Moderate	Low
	Moderate	Moderate	Moderate	Low
	Low	Low	Low	Low

- In the command line type the following formula:

Risk_Class:=Qualitative_Risk[Hazard_Class,Vulnerability_Class]

- Display the result and evaluate it. Also make a histogram and calculate the area and percentage that has low, moderate and high risk.

12 QUANTITATIVE LANDSLIDE RISK ASSESSMENT ALONG A TRANSPORTATION CORRIDOR: THE CASE STUDY OF NIGIRI, INDIA.



Expected time: 4 hours
Data: **Exercise_Nilgiri_QRA.zip** Size: 83 Kb
Objectives: After this exercise you will be able to generate:

- Carry out a quantitative risk assessment along a railroad and a road
- Use existing landslide inventory to estimate the frequency of landslides
- Calculate the direct risk to the infrastructure, the vehicles and the people in the vehicles
- Calculate the indirect risk due to interruption of the infrastructe.
- Use Excel to make these calculations.

12.1 INTRODUCTION

Landslide is one of the major natural risks along transportation corridors. To reduce the disastrous impact of landslides on society and to facilitate a rationale for land use planning, landslide risk quantification forms a fundamental tool in risk management process (Fell et al., 2005, 2008). Estimation of risks associated with landslides, therefore, becomes important in developing proper disaster management policies.

The landslide risk definition given by Varnes (1984), which includes loss to properties and lives and disruption of economic activities, is very appropriate for a transportation corridor where the risk is both direct, affecting the properties and people, and indirect, disrupting economic activities. Direct risks are the cost for restoration and repair of infrastructure, damages to vehicle, and loss of lives, whereas indirect risk affects the society by disrupting the utility services and local businesses, thereby incurring loss of revenue, tourism and increase in cost of day to day commodities (van Westen et al., 2006).

12.2 METHODOLOGY FOR QUANTITATIVE RISK ANALYSIS

In this section methods for estimation of both direct and indirect landslide risk due to cut slope failure along a road and a railroad corridor will be discussed. To assess direct risk to the physical infrastructural components (features of the railway line and road), vehicles and commuters, the following activities are required (Fell et al., 2008):

(1) assessment of landslide hazard for slides from cut slopes,
(2) quantification of elements at risk, including persons and property potentially affected by landsliding,
(3) assessment of temporal probability of the elements at risk to be in an exposed position,
(4) assessment of probability of the landslide reaching the elements at risk, and
(5) assessment of the vulnerability of the elements at risk, in terms of property damage (monetary loss) or loss of life.

The estimation of indirect risk depends on the socio-economic condition of the area of interest. It requires determination of the most important elements and activities in the area and how they could be affected due to the disruption (Remondo et al., 2008). The elements that are indirectly affected due to the traffic disruption include local businesses, residents, tourists, and transport department.

As a first step of the risk analysis, specific risk is estimated individually for each element at risk for a specific landslide hazard and then total risk is calculated by adding all the specific losses of both direct and indirect risks, separately for the property loss and the loss of life.

Assessment of landslide hazard
Landslide hazard analysis is often carried out to estimate risk to life and property or to facilitate future land use planning. In literature different methods have been used to quantify hazard depending on the quality of landslide inventory, the type of landslides, the scale of the study and the aim of the analysis.

Along the road and the railroad, landslides occur frequently from untreated cut slopes, e.g., in Nilgiri it is 43 slides per year. Landslides initiating from cut slopes are generally small in size but pose considerable risk to life and property, as they may directly affect vehicles and persons below. To quantify risk along a road or a railroad, we require the estimation of the frequency of landslides (i.e., number of landslides per annum) and the degree of loss to specific elements at risk resulting from the specified landslide magnitude (AGS, 2000; Fell et al., 2005, 2008). Researchers have used different statistical models to estimate frequency of landslides, such as those based on the probability density function of landslide volumes (e.g., Hungr et al., 1999), exceedance probability of a rainfall threshold (Jaiswal and van Westen, 2009) and the exceedance probability of landslides based on Poisson or Binomial probability models (e.g., Coe et al., 2000; Guzzetti et al., 2002, 2005). The models based on rainfall threshold provide an estimate of the exceedance probability of one or more rainfall events that can trigger landslides, whereas those based on the occurrence of past landslides provide exceedance probability of one or more landslides that can occur in an area. Both threshold and landslide based-models are ultimately used to obtain the probability of occurrence of one or more landslides in a specified time period. For transportation lines, specific information on the expected number of landslides and their annual probability of occurrence (or return period) are important for estimating direct and indirect risk, expressed in terms of annualised loss. This information is used to estimate the probability of a landslide hitting a moving vehicle or a commuter (AGS, 2000; Wilson et al., 2005) and to calculate the blockage time by estimating the total volume of debris on the transportation line.

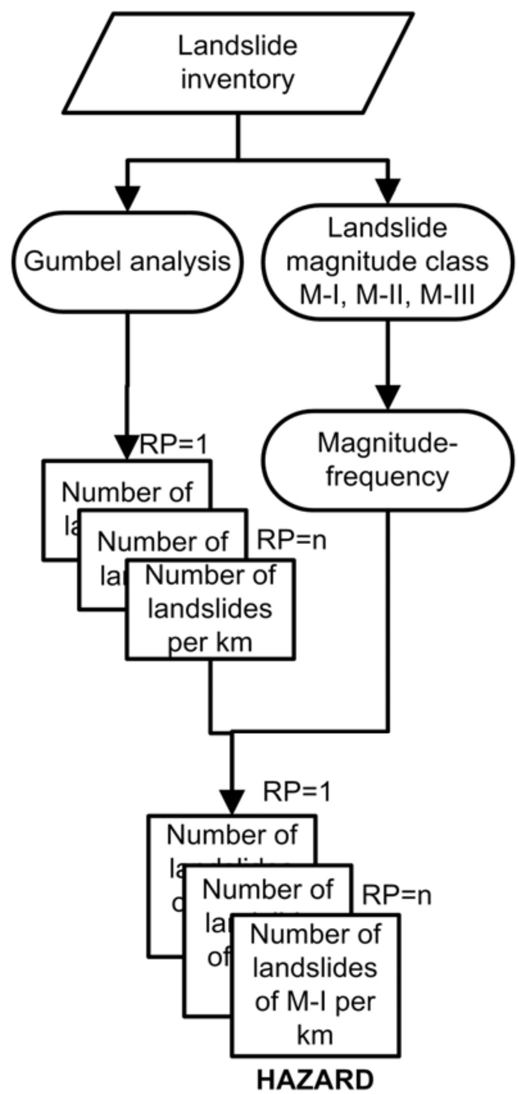


Fig. 1 shows the work flow of the approach used to estimate landslide hazard from cut slope failures along the road and railroad. For the hazard calculation, it is assumed that the probability of landslide occurrence can be calculated directly from the complete landslide inventory by analyzing the number of expected landslides per kilometer of the (rail) road for different return periods. For this the Gumbel method for frequency-magnitude analysis in which the magnitude is represented as the number of landslides per kilometer is used. The volume of expected landslides was analyzed separately using the volume-frequency analysis. The hazard, expressed as the probability of a given number of landslides with a particular volume to occur along a specific section of the road or railroad, was obtained by multiplying the probability of having a certain number of landslides per unit length resulting from the Gumbel analysis, with the results of the volume-frequency analysis (Table1)

Table 1. Magnitude class for landslides on cut slopes and Probability of occurrence.

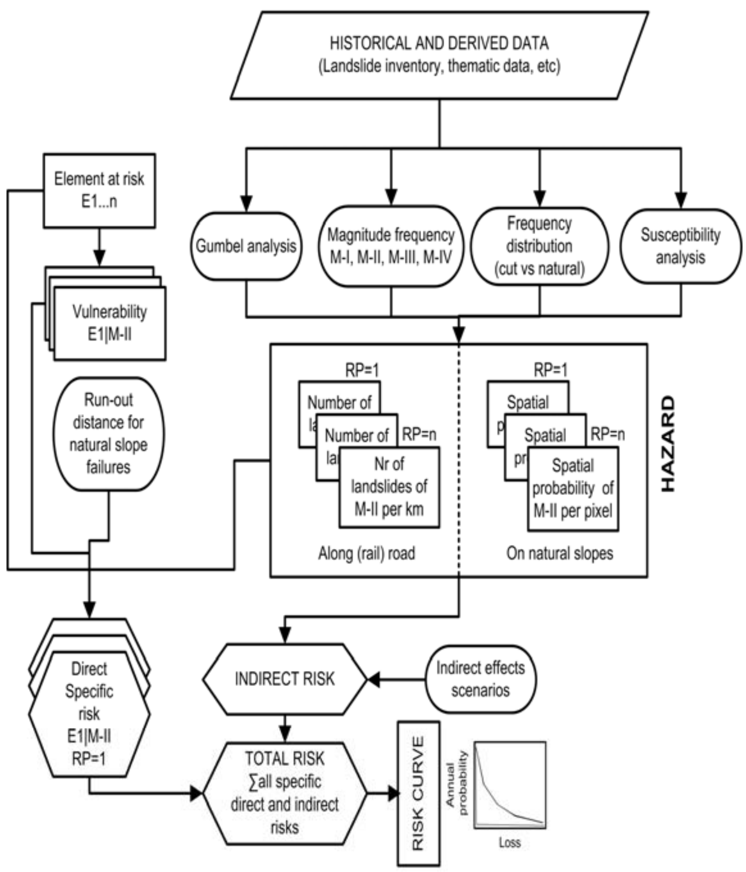
Size class	*V*, range (m^3)	*Sd* (m)	*RD* (m)	*Ad* (m)	*P, range (average)* <100 slides/ year*	≥100 slides/year*
M-I	$< 10^2$	<1	< 10	1	0.5-1 (0.85)	0.39
M-II	10^2-10^3	< 2	10-50	< 2	0.01-0.33 (0.13)	0.53
M-III	$>10^3$	2- 8	>50	< 5	0-0.16 (0.02)	0.08

V is the volume of landslide at source, *Sd* is depth of scar, *RD* is run-out distance, *Ad* is depth of accumulated debris, and *P* is probability of occurrence.
* is the triggering event resulting in < 100 or ≥100 slides in the study area.

For detail on hazard analysis please refer Jaiswal et al. (2010a and 2011a).
Note: for linear infrastructures the specific loss in a given return period is directly related to the number of landslides of a given size occurring along different sections (e.g., per km) the infrastructure.

Estimation of direct risk

Direct risk can be estimated for elements that can be directly affected by landslides along the transportation lines, such as the physical infrastructural components (components of the railway line and road), vehicles (trains, buses, trucks, cars and motorbikes), and people (road and train users).



Direct risk to the infrastructure components

For the calculation of the direct risk to the infrastructure components, the following equation is used (adapted from Fell et al., 2005):

$$RD_{EaR} = \sum_{m=1}^{m=n} (H_m \times P_{Lm:EaR} \times P_{T:EaR} \times V_{EaR:Lm} \times A_{EaR}) \quad (1)$$

where, RD_{EaR} is the direct risk to the element at risk, H_m is the hazard due to landslides of magnitude class '*m*' (#/km), $P_{Lm:EaR}$ is the probability of a landslide with magnitude '*m*' reaching the element at risk (0-1), $P_{T:EaR}$ is the temporal probability of the element at risk to be exposed to a landslide of magnitude '*m*' (0-1), $V_{EaR:Lm}$ is the vulnerability of the element at risk (degree of loss) caused due to the occurrence of a landslide of magnitude '*m*' (0-1), and A_{EaR} is the quantification (monetary value) of the element at risk. The specific risk is calculated per standard length of the road or railway line (e.g. per kilometer). The specific risk for different landslide magnitudes is added for each return period to generate the combined specific risk for a particular infrastructure element.

The value of $P_{T:EaR}$ can be taken as 1 as these elements are stationary objects. The value of $P_{Lm:EaR}$ is also taken as 1 because the infrastructure components are located below the cut slopes and landslides from these cut slope invariably reach them. The assessment of the vulnerability of the railway line and the road is generally based on the information obtained from historical events in the area.

For the (rail) road, vulnerability is calculated as the ratio of the total restoration cost (US$/m) of the damaged structure due to a landslide of a given magnitude to the actual construction costs per unit length of the structure (US$/m) without taking into account the construction of bridges and the slope cutting. The total restoration costs include the costs of removing landslide debris from the (rail) road and those of replacing the damaged components. Vulnerability for the railway line and the road for landslides of different magnitude classes are given in Table 2.

Direct risk to vehicles

Direct risk to a moving vehicle, i.e. a vehicle being hit by a landslide, depends on the probability ($P_{T:EaR}$) of the vehicle being at the location of a landslide when it occurs. This probability ($P_{T:EaR}$) is used to calculate the risk to a moving vehicle for a given return period using the following three expressions (adapted from AGS, 2000):

$$RD_v = P(V_m) \times V_{veh:m} \times A_{veh} \quad (2)$$

$$P(V_m) = 1 - (1 - P_{T:EaR})^{Nr} \quad (3)$$

$$P_{T:EaR} = (ADT \times L)/(24 \times 1000 \times S_{veh}) \quad (4)$$

where, RD_v is the direct risk to a vehicle (US$), $P(V_m)$ is the probability of one or more vehicles being hit by a landslide with a magnitude '*m'* (0-1), $V_{veh:m}$ is the vulnerability of the vehicle for a landslide of magnitude '*m'* (0-1), A_{veh} is the cost of the vehicle (US$), $P_{T:EaR}$ is the temporal probability the vehicle at risk is exposed to a landslide of magnitude 'm' (0-1), N_r is the number of landslides of magnitude '*m'*, *ADT* is the average daily traffic (vehicles per day), *L* is the average length of the vehicle (m) and S_{veh} is the speed of the vehicle (km/hr). To calculate risk to a single vehicle the value of ADT in Eq. (4) is set to 1. Different examples of calculation of landslide risk along roads are given in Fell et al. (2005).

Table 2 Estimated vulnerability of elements at risk affected by a landslide from cut slopes.

Element at Risk	Vulnerability due to a landslide of magnitude class		
	M-I max*	M-II max*	M-III max*
Infrastructure			
Railroad	0.5	1	1
Road	0.2	0.4	0.8
Moving vehicle			
Bus	0.01	0.1	0.8
Lorry	0.01	0.1	0.8
Car	0.1	0.5	1
Motorbike	0.5	0.8	1
Train	1	1	1
Person in a moving vehicle (probability of death)			
Bus	0.001	0.1	0.8
Lorry	0.001	0.1	0.8
Car	0.01	0.1	1
Motorbike	0.5	1	1
Train	0.5	0.5	0.5

* is the upper limit of the magnitude class.

The parameters required for Eqs. (2-4) can be obtained from historical incidents and field calculations. The assessment of vulnerability of different types of moving vehicles can be carried out based on historic incidents e.g., landslides hitting moving vehicles, however due to the lack of such incidents the assessment of vulnerability is somewhat subjective (Table 2).

When calculating the risk to the property it is often assumed that all landslides of a given magnitude class in a given return period have the same volume which is used in the estimation of the vulnerability. Since the vulnerability was estimated from the maximum volume in a given magnitude class the calculated risk gives the maximum loss in a given return period.

Direct risk to loss of life

The risk of life or the annual probability of a person losing his/her life while travelling in a vehicle depends on the probability of the vehicle being hit by a landslide and the probability of death of the person (vulnerability) given the landslide impact on the vehicle. The vulnerability of commuter to a landslide depends on the type and size of the landslide, the speed and type of the vehicle, and whether the person is in the open or inside a vehicle, or whether the debris directly hits the vehicle from the top or from the side. The vulnerability of people when a vehicle is hit by landslides of different magnitude classes is given in Table 2.

The specific risk to people for a given return period is estimated using the following expression (adapted from AGS, 2000):

$$R_p = P(V_m) \times V_{p:m} \tag{5}$$

where, Rp is the annual probability of death (0-1), $Vp{:}m$ is the vulnerability of the individual (probability of death) given the landslide impact on the vehicle (0-1). The parameter $P(V_m)$ is estimated using Eqs. (3-4). For a single vehicle being hit by a landslide, the value of ADT in Eq. (4) is set to 1.

Using Eq. (5) and setting ADT to 1, the specific risk in terms of annual probability of the person most at risk losing his/her life by travelling in different type of vehicles can be calculated for each hazard scenario.

Estimation of indirect risk

The indirect risk estimation requires two basic parameters: the hazard scenario that defines the blockage time of the transportation lines, and a socio-economic analysis of the study area to determine the most important activities in the area and their consequences to the society if disrupted.

Here we provide methods to analyze four types of indirect losses resulting from the temporal blockage of the transportation lines: additional fuel consumption; additional travel cost; loss of income to the local business; and loss of revenue to the railway.

At first step identify the alternate driving routes in case of the blockage of the main line. Indirect combined risk for additional fuel consumption for a given return period is calculated using the following expression:

$$RI_{FC} = \sum_{m=1}^{m=n} \left[(ARL \times ADT \times FC \times TBT_m) / M_V \right] \tag{6}$$

where, RI_{FC} is the indirect combined risk (monetary loss) due to additional fuel consumption by vehicles (US$), *ARL* is the alternate road length (km), *ADT* is the average daily traffic (vehicles per day), *FC* is the fuel cost (US$/l), TBT_m is the traffic blockage time due to landslides with magnitude '*m*' (day) and M_V is the mileage of the vehicle (km/l).

Traffic blockage time can be obtained by dividing the total volume of debris (m^3) on the road by the average debris clearance rate (m^3/day). The total volume of landslide debris is calculated from the hazard, which provides the number of landslides of magnitude classes M-I, M-II and M-III from cut slopes along the road. The number of landslides was multiplied by the median volume of each magnitude class to obtain the total volume of debris.
Indirect combined risk for additional travel cost for a given return period is calculated using the following expression:

$$RI_{TC} = \sum_{m=1}^{m=n} ADC \times CT \times TBT_m \quad (7)$$

where, RI_{TC} is the indirect combined risk (monetary loss) due to additional travel cost (US$), *ADC* is the average commuters per day, *CT* is the cost of ticket (US$) and TBT_m is the traffic blockage time due to landslides with magnitude '*m*' (days).

Indirect combined risk for business for a given return period is calculated using the following expression:

$$RI_B = \sum_{m=1}^{m=n} NBT \times ADI \times P_{Loss} \times TBT_m \quad (8)$$

where, RI_B is the indirect combined risk (monetary loss) to business (US$), *NBT* is the number of businesses, *ADI* is the average daily income from the business (US$/day), P_{Loss} is the probability of loss in income (0-1) and TBT_m is the traffic blockage time due to landslides with magnitude '*m*' (days).

Indirect combined risk to the railway department in a given return period is calculated using the following expression:

$$RI_R = \sum_{m=1}^{m=n} DIL \times TBT_m$$

(9)
where, RI_R is the indirect combined risk (monetary loss) to the railway department (US$), *DIL* is the daily income loss (US$/day) and TBT_m is the traffic blockage time due to landslides with magnitude '*m*' (days).

Estimation of total risk

The total landslide risk is the summation of all the specific risks related to landslides in an area including the indirect risks. The total landslide risk of monetary loss is calculated by adding the total risk, including both direct and indirect losses of a given return period. The output was plotted as a risk curve, containing the relation between hazard with different annual probabilities and the corresponding total losses. The area under the curve gives the total annualized loss in the study area.

12.3 DESCRIPTION OF DATA SET (EXCEL FILE NAME: EXAMPLE_RAIL)

The data set belong to a railroad corridor in Nilgiri hills, Tamilnadu, India. The railroad is 17 km long excavated in 1908 (Fig. 1).

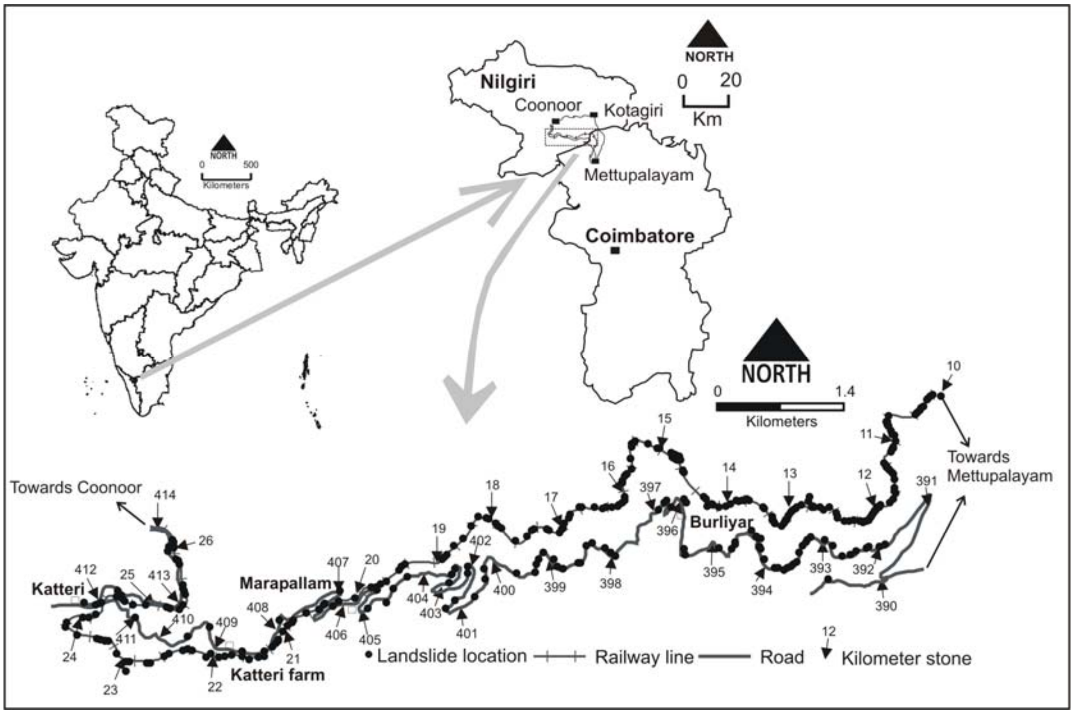


Fig. 1. Location of the road and the railway alignment. Black circles are the location of landslides.

Landslides occur frequently on cut slopes along the railroad due to rain. These are mostly as debris slides or debris flowslides. An inventory of a total 796 landslides was prepared from the railroad maintenance records, including information on the date of landslides, volume and location.

In the excell file (name: **Example_rail**), the total number of landslides per kilometer section is given for the period 1987 to 2007 (refer excel sheet: slide data). Also data on temporal distribution of landslides per kilometer section is given. Landslides are grouped into 3 classes (M-I, M-II and M-III), see Table 1.

12.4 HAZARD ANALYSIS

The hazard here is expressed as the probability of a given number of landslides with a particular volume to occur along a specific section of the railroad.

To estimate landslide frequency and return period in different kilometer sections of the railroad. For detail see Jaiswal et al., 2011a

1. Open the excel file (name: **Example_rail**). Select/copy the temporal landslide data for the desired kilometer section, say km-14 from file name: slide data. Now open excel file (name: Gumbel) and paste the selected data as indicated in the sheet itself.
2. Sort the slide data in the decreasing order and enter in column E of sheet name: Gumbel (excel file name: Gumbel). Note the straight line equation in the gumbel plot. Solve the same for different values of x or y (see column P108-P112, in sheet name: Gumbel result, excel file: Example_rail). Read the return period and annual probability for the corresponding value of y from sheet name: RP (excel file name: Gumbel).
3. Using Gumbel eq. obtain the number of landslides in 1, 3, 5, 15, 25 and 50 years return period for every kilometer section, refer sheet name: Gumbel result. Write the result against each kilometer section. Multiply each value with the probability of landslide magnitude to obtain hazard per km section.

NOTE: The results show that in total 70, 112, 195, 230 and 279 landslides are expected to occur along both the road and railroad in T_3, T_5, T_{15}, T_{25} and T_{50} year return period, respectively (For detail explanation please refer Jaiswal et al., 2011a). More than 100 landslides are expected on average once in five or more years and therefore the probability of landslide magnitude for T_5, T_{15}, T_{25} and T_{50} is taken as 0.39 for M-I, 0.53 for M-II and 0.08 for M-III. For T_3 return period, with less than 100 landslides, the probability is taken as 0.85 for M-I, 0.13 for M-II and 0.02 for M-III.

The answer for different kilometer sections is given in sheet name: Gumbel result, excel file name: Example_rail. The result of the final gumbel analysis and an example of hazard calucation for a RP=50 year along the railroad are also given in sheet name: Gumbel result, excel file name: Example_rail.

The results indicate that no landslide is expected to occur along the railway line on average once every year. Total 56, 84, 140, 164 and 197 landslides are expected to occur along the railway line in T_3, T_5, T_{15}, T_{25} and T_{50} years return period, respectively.

Once the hazard is analyzed the next step is to use these values in risk estimation.

12.5 ESTIMATION OF DIRECT RISK

Direct risk to the infrastructure components

- First the specific risk is to be calculated separately for each magnitude class and return period. For each magnitude class the corresponding vulnerability value can be taken from Table 2. The value for $P_{Lm:EaR}$ (the probability of a landslide with magnitude '*m*' reaching the element at risk) and $P_{T:EaR}$ (the temporal probability of the element at risk to be exposed to a landslide of magnitude) are taken as 1.
- Click on column N8, T8 and Z8 of sheet name: risk_railroad, excel file name: Example_rail and look at the function. The input here is hazard, vulnerability, spatio-temporal probability and amount as given in Eq (1). It directly calculates the specific loss in US$ per km of the railroad.

NOTE: the amount (cost) and vulnerability is measured in per m. But in the analysis the loss is estimated per km. This is because the loss from a single slide is multiplied by the total number of landslides expected per km section. Also note the inclusion of an additional parameter i.e., 'the length of railroad affected by a slide' (see column D31-33 in sheet name: risk railroad). This is because each slide causes damage more than one meter.

- Calculate the combined risk by adding loss per return period. For this add the loss per return period resulting from the three magnitude class. This can be done separately for each kilometer section or for the entire railroad. In this example the combined loss for the entire railroad is given (refer sheet name: risk railroad, column F34 to J34).

Direct risk to moving train

The parameters required for Eqs. (2-4) were obtained from historical incidents and field calculations. The average speed of the train was measured as 11 km/hr. The ADT value was taken from the train time table, which is two per day. The average length (L) of a train was measured as 55 m.

- First calculate $P_{T:EaR}$ using Eq. (4). For a single train the value of ADT is set to 1. Next calculate $P(V_m)$ using Eq. (3). N_r here is calculated for each day for each magnitude class by dividing the frequency of landslides (hazard) by 365.
- The specific risk is calculated separately for each magnitude class and return period. For each magnitude class the corresponding vulnerability value can be taken from Table 2 (refer sheet name: risk_train, excel file name: Example_rail).To calculate risk to one or more train, use the value of ADT in Eq. (4).
- Calculate the combined risk by adding loss per return period. For this add the loss per return period resulting from the three magnitude class. In this example the combined loss for one or more train is given (refer sheet name: risk train, column E47 to J34).

Direct risk to loss of life of train passengers

- First calculate $P(V_m)$ as indicated above by taking ADT as 1. Multiply the value with vulnerability to obtain the person most at risk (refer sheet name: risk_life, excel file name: Example_rail).

- Calculate the combined risk by adding loss per return period. For this add the loss per return period resulting from the three magnitude class. In this example the combined loss of life is given (refer sheet name: risk life, column I19 to M19).

12.6 INDIRECT RISK (LOSS OF REVENUE TO THE RAILWAY)

This requires estimation of the income to the railway and the total blockage time of the railroad.The daily income includes revenue generated from the sale of tickets, which is on average US$ 280/day. The traffic blockage time due to landslides was estimated from historical damage data obtained from the railway office. The data provided the total blockage time in different years (i.e., days when the railroad was closed for the traffic) and the amount of debris that were cleared from the railroad and the repair works that were carried out. The blockage time was found to vary from 4 to 134 days depending on the volume of debris and type of repair works needed for the restoration of the railroad. A scatter plot was generated between the total volumes of debris (in m^3) on the railroad and total blockage time (days) in the period 1992 to 2007. The relation has a power law distribution with power law exponent as 0.62 and constant as 0.31. The coefficient of correlation was obtained as 0.65. This relation was used to calculate the expected traffic blockage time due to landslides with magnitude '*m*' with a given return period. The traffic blockage time estimated to vary from 16 to 175 days depending on the total volume of material on the railroad (refer sheet name: indirect risk, excel file name: Example_rail). .

- First calculate DIL (Daily income loss) which here is US$ 280 from the sales of ticket (refer sheet name: indirect risk, excel file name: Example_rail).
- Calculate TBT using the relation [Blockage day = 0.3118 H volume $^{0.6222}$]. Now multiply DIL and TBT for each magnitude class for a given return period. For total volume of debris per magnitude class, multiply the number of landslides with the median volume obtained from the inventory, which is 18 $m^3$for M-I, 200 m^3 for M-II and 1680 m^3 for M-III.
- Calculate combined risk by adding loss per return period. For this add the loss per return period resulting from the three magnitude class. In this example the combined indirect loss is given (refer sheet name: indirect risk, column M22 to S22).

12.7 TOTAL RISK

- In a excel sheet add all losses (both direct and indirect) for different return periods (refer sheet name: total, excel file name: Example_rail). The inverse of return period is the annual probability.
- Draw a graph between the annual probability (y-axis) and corresponding total loss in x-axis. This is called RISK CURVE. The area under curve is the total annualized loss. Now calculate total annualized loss as shown in sheet name: total, excel file name: Example_rail. In this case the total annual loss is about US$ 128,500.

NOTE: The risk curve can be used to compare loss from different hazards in an area. This can also be used in cost-benefit analysis where the benefit is the total annual loss that is to be minimized by different mitigation options.

12.8 ADDITIONAL EXERCISE: RISK ALONG THE ROAD (EXCEL FILE NAME: EXERCISE)

In this exercise we will hazard data along the road to quantify direct and indirect risks. The hazard includes the number of landslides in different return periods estimated for two sections of the road.

Along the road, data on the occurrence of landslides were not available for every kilometer, and therefore, the Gumbel analysis was performed on two larger sections: a section with a length of 10 km (S-I, from km-390 to km-400) and a section of 14 km length (S-II, from km-400 to km-414). The two sections were selected on the basis of the difference in geomorphological setting and the density of landslide scars, which is the percentage of length of the road covered by landslide scars. In section S-I, the average density is 14 km^{-1}, which is about three times higher than in section S-II. The average landslide density for the entire road is about 9 km^{-1}.

The data also include ADT for different types of vehicles, their average length in m, their cost in US$, their average speed, their vulnerability for different landslide magnitudes, and probability of landslide magnitude (see excel file name: Exercise).

The following addition information is also available:

- Length of road damaged by a landslide of magnitude M-I is 10m, M-II is 50m and M-III is 75 m,
- The road from Mettupalayam to Coonoor via Kotagiri covers an extra distance of 32 km.
- The ADT for local Nilgiri vehicles is 120 for bus, 219 for lorry, 222 for car and 19 for motorbike. The ADT for tourist vehicles is 45 for bus, 331 for car and 70 for motorbike
- The fuel cost was established as US$ 0.8 per litre, which is the average value of diesel and petrol cost in the Nilgiri area in 2007.
- The mileage (fuel consumption per liter) also varies according to vehicle type, which is 5, 4, 10 and 30 km/l for a bus, lorry, car and motorbike, respectively.
- The median value of landslide volume for each magnitude class was obtained from the landslide inventory, which is 18, 200, 1,680 m^3 for landslides of M-I, M-II and M-III class, respectively.
- The average clearance rate along the road is 1,064 m^3 of debris per day.
- Every day on an average 120 local buses pass via Coonoor with an average capacity of 50 passengers. To calculate the additional cost of travel, assume that each bus carries at least 50 passengers who have to pay additionally US$ 0.13 per journey.
- The average loss of each business was obtained by participatory survey. In Katteri, the average loss to hotels, wine shop and general shops is approximately 75, 50 and 30%, respectively and around Burliyar it is 100%. In Katteri the total number of hotels, wine shop and general shops is 2, 1 and 6, respectively with their daily income as US$ 4, 362 and 11, respectively. In Burliyar there are 35v shops with daily income as US$ 2.

- Estimate direct risk to the infrastructure component (road).
- Estimate direct risk to a moving vehicle i.e., vehicle most at risk (a bus, a lorry, a car and a motorbike).
- Estimate direct risk to loss of life to a commuter (person most at risk).
- Estimate indirect losses resulting from the temporal blockage of the road: additional fuel consumption; additional travel cost and loss of income to the local business.
- Calculate total risk and generate risk curve. Calculate total annualized loss

12.9 REFERENCES

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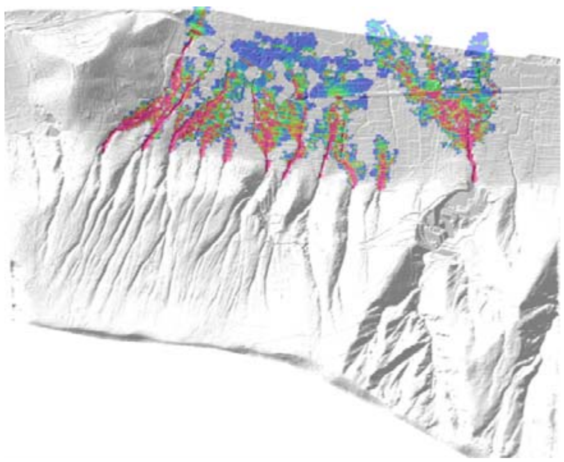
13 QUANTITATIVE MULTI-HAZARD RISK ASSESSMENT AT LOCAL SCALE: THE CASE STUDY OF NOCERA, ITALY.



Expected time: 4 hours
Data: **Exercise_Nocera.zip** Size: 42 Mb
Objectives: After this exercise you will be able to generate:

- Carry out a quantitative risk assessment for floods, hyperconcentrated flows, debris flows and landslides
- Calculate the number of buildings exposed to each of the hazard types
- Apply vulnerability matrices for estimating the vulnerability to the various hazard types.
- Calculate the risk as individual risk, societal risk and economic risk.

13.1 INTRODUCTION

This tutorial shows you the steps required to carry out a quantitative multi-hazard risk assessment using GIS. Given the short time available for the tutorial and the many steps required in a risk analysis, we have made a series of script files, in which the various GIS operations are combined, so that you do not need to learn how to work with the GIS, but can concentrate on the method, the data requirements and the output.
The dataset is for the Monte Albino area, in Nocera Inferiore. In the context of the EU SAFELAND project on landslide risk management (www.safeland-fp7.eu/) the University of Salerno has collected a large amount of data for the hazard and risk analysis of this area.

The method that we will be using in the GIS tutorial will closely follow the document Deliverable 2.11 (QRA case studies at selected "hotspots"). This document is available as background reading material. The Monte Albino area is threatened by the following types of hazards:

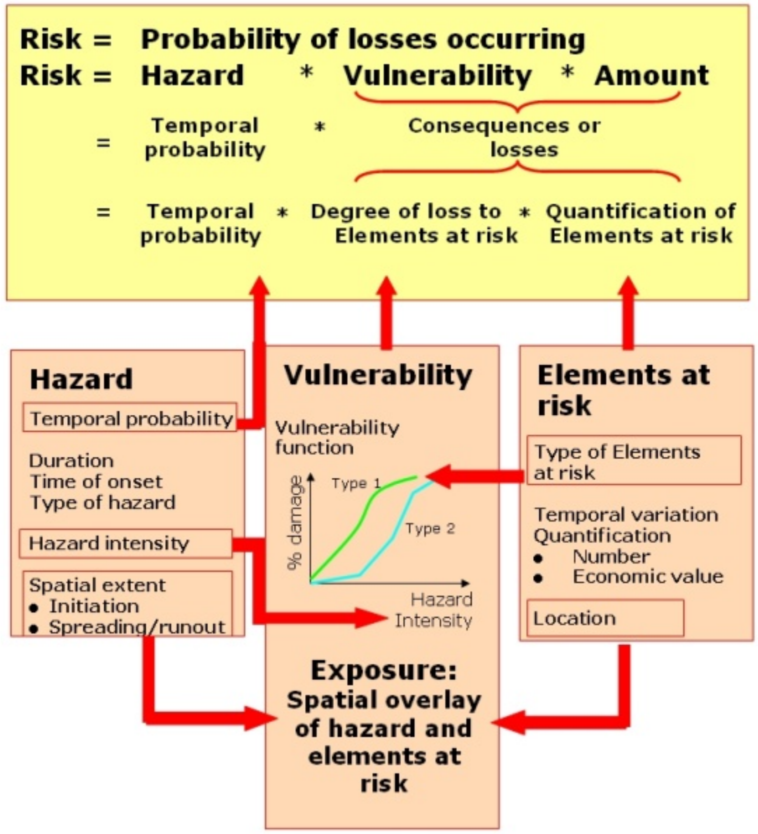
- **Hyperconcentrated flows** related to erosion processes originated by heavy rains and affect the pyroclastic soils cover along rills as well as on the inter-rills areas.
- **Flashfloods** are originating from heavy rains as well, and they are having less sediment load than the hyperconcentrated flows.
- **Landslides** on the open slope sections, affect the triangular facets located at the base of the slope; they have similar characteristics to the phenomenon occurred on March 2005 (see figure) and are classifiable as "debris avalanches"
- **Mudflows** from flowslides that originate higher up in the catchment.

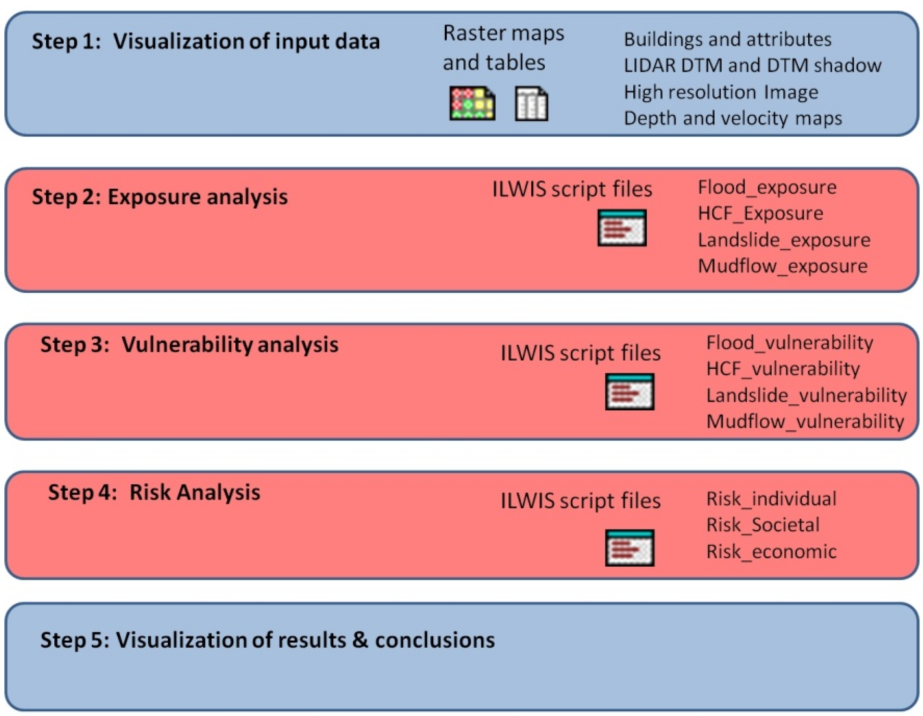
For the analysis of the hazard different approaches were used by the team of the University of Salerno, which are summarized in the table below. In this tutorial there is no time to go into details about the parameters used in the hazard assessment. It should be noted that for some hazards (floods) we have several scenarios (one for 20 year RP and for 100 year RP), whereas for the others we only have one scenario. This will not allow to calculate a complete quantitative multi-hazard risk, which requires for each hazard at least 3 scenarios with different return periods, in order to generate risk curves. Instead we will focus on the risk of the available scenarios.

Hazard type	Scenario	Return period	Hazard assessment	Files
Flooding	2 scenarios modelled	- 25 years - 100 years	FLO-2D	Flood_depth_020y Flood_depth_100y Flood_velocity_020y Flood_velovity_100y
Hyperconcen-trated flow	3 scenarios with different input parameters	- 17 years (before) - 200 years rainfall event used in the analysis	FLO-2D based on T=200 year rainfall	HCF_depth_sc1 to sc3 HCF_velocity_sc1 to sc3
Landslides	1 scenario	- 18.5 years	Empirical assessment of runout zones	Landslide_SF Landslide_distance Landslide_runout
Mudflows	1 scenario	- 200 years rainfall event	Safety factor analysis TRIGRS, runout with FLO-2D	Mudflow_depth Mudflow_velocity

13.2 STRUCTURE OF THE TUTORIAL

The structure of the GIS tutorial is shown below. There are 5 steps, starting and ending with the visualization of input and output data. We will only focus on buildings and population in this analysis. The analysis steps are 3: exposure analysis (which buildings are exposed and what is the hazard intensity), vulnerability analysis (what is the relation between the hazard intensity and the degree of damage) and the risk analysis (individual risk, societal risk and direct economic risk). Each step will take approximately 20 minutes.


Risk = Probability of losses occurring
Risk = Hazard * Vulnerability * Amount
= Temporal probability * Consequences or losses
= Temporal probability * Degree of loss to Elements at risk * Quantification of Elements at risk
Hazard
Temporal probability
Duration
Time of onset
Type of hazard
Hazard intensity
Spatial extent
Initiation
Spreading/runout
Vulnerability
Vulnerability function
% damage
Type 1
Type 2
Hazard Intensity
Elements at risk
Type of Elements at risk
Temporal variation
Quantification
Number
Economic value
Location
Exposure: Spatial overlay of hazard and elements at risk


Step 1: Visualization of input data
Raster maps and tables
Buildings and attributes
LIDAR DTM and DTM shadow
High resolution Image
Depth and velocity maps
Step 2: Exposure analysis
ILWIS script files
Flood_exposure
HCF_Exposure
Landslide_exposure
Mudflow_exposure
Step 3: Vulnerability analysis
ILWIS script files
Flood_vulnerability
HCF_vulnerability
Landslide_vulnerability
Mudflow_vulnerability
Step 4: Risk Analysis
ILWIS script files
Risk_individual
Risk_Societal
Risk_economic
Step 5: Visualization of results & conclusions

13.3 VISUALIZATION OF THE INPUT DATA

First we are going to visualize the input data. ILWIS 3.08 Beta has an entirely new interface for data visualization which we will explore in this section.

- Unzip the data in a directory on the harddisk (C or D drive, and not on desktop)
- Open the ILWIS program and navigate to the directory where you stored the data.
- Double click on the raster map **IMAGE** . You can zoom in on certain areas, and use the upper left icon to display the entire image.

We will now see some of the input data for the exercise. We first display the flood map as example

- Double click on the raster map **DTM_SHADOW** . Select Layer/ Add layer and add the map **Flood_depth_020y** with Tranparency and increase the transparency to 50%, and include in the Stretch the upper value to 0.29 or so. You can now see the flood depth map displayed on top of the hillshading image. Move with your mouse over the map and read the values of the flood depth in the lower left corner.

You can also consult all the other maps at the same time using the Pixel Information window at the bottom right.

- Open the Pixel Information window by clicking the Pixel Information button in the main window, and select Add Map. Add the map: **Flood_depth_100y**. Do the same for the maps **HCF_depth_sc2**, **Landslide_distance**, **Mudflow_depth** etc. You can then read the values for all maps for the same areas.

We can also add the building information.

- Add the polygon map **Buildings**. Zoom in on some of the building and move with the pointer over them. Observe the information that is available for each of the buildings: Building materials (e.g. masonry), floors (number of floors), occupancy (e.g. residential), people (maximum number of people present in the building), area (area of the building in square meters) and value (value of the building and contents in Euros).

We will only use the building and population information in the exercise as the type of elements at risk. There is also road information.

- Experiment a bit with displaying the hazard and elements at risk maps for some minutes.

13.4 EXPOSURE ANALYSIS

In the exposure analysis we are going to make a spatial overlay between each of the hazard maps and the building map, and calculate the maximum depth and velocity of hyperconcentrated flows, floods and mudflows for each building. We are also going to calculate how many buildings are exposed to each of these types of hazards. For landslides we are analyzing how far the house is located from the toe of the unstable slope (what the runout length is) and also how far the landslide moves further than the building. The table below gives an overview of the 4 hazards, the input maps and the scripts that will be used.

Hazard and script file used.	**Name of hazard maps**	**Description**
Floods Flood_exposure	Flood_depth_020y Flood_velocity_020y	Flood depth & velocity modeled with FLO-2D with rainfall event that has a 20 year return period
	Flood_depth_100y Flood_velocity_100y	Flood depth & velocity modeled with FLO-2D with rainfall event that has a 100 year return period
Hyperconcentrated flow HCF_exposure	HCF_depth_sc1 to HCF_depth_sc3 HCF_velocity_sc1 to HCF_velocity_sc3	Depth and velocities modeled with FLO-2D with rainfall event of 200 year return period with 3 different sets of parameters for the model to represent the uncertainty.
Mudflow Mudflow_exposure	Mudflow_depth Mudflow_velocity	Depth and velocities modeled with TRIGGRS and FLO-2D with rainfall event of 200 year return period
Landslide Landslide_exposure	Landslide_distance	Emperically derived distance of the runout of landslides from 10 open slopes in between valleys
	Landslide_runout	File of the 10 runout areas with information in the attribute table on the relative stability of the slope above and the maximum runout.

Let us look at one of the scripts.

- Open the script **Flood_exposure**. The file contains a number of lines of code. Each line represents a specific command or operation in ILWIS. Lines starting with // contain some explanations. It would go too far here to explain all individual steps in the script, what what the script does is to overlay the hazard map with the building map (operation called TableCross), and to read in the maximum values in an attribute table of the building (operation ColumJoin Max). You can run the script by pressing the black triangle button in the window. Now one by one the lines of the script are executed. The results are shown in a table which is opened after completing the script (make sure that in the table in View the View statistics Pane is selected).

In the resulting table you can see that there are now values for the maximum height and velocity of flood for events with 20 and 100 years return period (h020, h100, v020, v100). You can also see how many buildings in total have been flooded in the two events (nr_buildings_flooded)

- Write the values for the number of affected buildings in the table below. Now run the scripts also for the other hazards. And write the number of affected buildings also in the table below.
    - Which of the hazards has the largest number of exposed buildings?
    - Does that also indicate that the risk is the largest for that type of hazard?

	Flooding	Hyperconcentrated flows	Landslide runout	Mudflow
Scenarios	020y	Sc1:		
		Sc2:		
	100y	Sc3:		

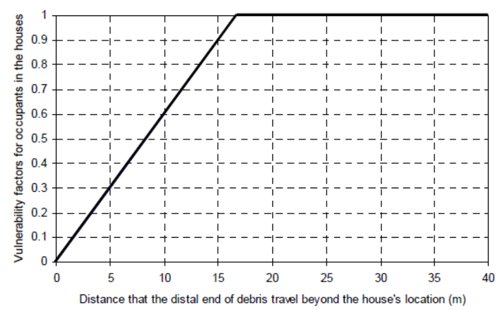
The resulting tables (Exposure_flood, exposure_hcf, exposure_landslide and exposure_mudflow) are required as inputs for the next step: vulnerability assessment.

13.5 VULNERABILITY ANALYSIS

In the vulnerability analysis we are going to use the hazard intensity values that we have calculated for each building in the exposure analysis and convert it is a value that represents the degree of loss. For this we need to make use of vulnerability curves, tables or matrices that relate the degree of intensity (in our case depth and velocity) to the vulnerability. As indicated in the SAFELAND report we are using 3 sets of vulnerability values indicated below.

Flood		Hyperconcentrated flow		Mudlfow	
h ≥ 1 and v ≥ 5	0.1	h ≥ 1 and v ≥ 5	0.15	h ≥ 1 and v ≥ 7	1
h ≥ 1 and 1≤ v < 5	0.05	h ≥ 1 and 1≤ v < 5	0.1	h ≥ 1 and 3 ≤ v < 7	0.8
0.5 ≤ h < 1 and v ≥ 5	0.05	0.5 ≤ h < 1 and v ≥ 5	0.1	0.5 ≤ h < 1 and v ≥ 7	0.8
h ≥ 1 and v < 1	0.025	h ≥ 1 and v < 1	0.08	h ≥ 1 and v < 3	0.4
0.5 ≤ h < 1 and 1 ≤ v < 5	0.025	0.5 ≤ h < 1 and 1 ≤ v < 5	0.08	0.5 ≤ h < 1 and 3 ≤ v < 7	0.4
h < 0.5 and v ≥ 5	0.025	h < 0.5 and v ≥ 5	0.08	h < 0.5 and v ≥ 7	0.4
0.5 ≤ h < 1 and v < 1	0.01	0.5 ≤ h < 1 and v < 1	0.05	0.5 ≤ h < 1 and v < 3	0.2
h < 0.5 and 1 ≤ v < 5	0.01	h < 0.5 and 1 ≤ v < 5	0.05	h < 0.5 and 3 ≤ v < 7 0.4	0.4
h < 0.5 and v < 1	0.005	h < 0.5 and v < 1	0.02	h < 0.5 and v < 3	0.05

- What do you think the result will be of applying these values in terms of the resulting risk? Do you think these values are realistic?



For landslide vulnerability another method is used that calculates the distance that the distal part of the landslide travels beyond the house location.

- What do you think the result will be of applying these values in terms of the resulting risk? Do you think these values are realistic?

The vulnerability analysis is also carried out using 4 scripts, once for each type of hazard.

- Open the script **Flood_vulnerability**. The various levels of vulnerability depending on the depth and velocity are calculated using a number of IFF, THEN, ELSE statements. In ILWIS these have the structure IFF(condition,then,else). In the end the intermediate results are deleted.
- Run the script Flood_vulnerability, by clicking on the triangle icon. Check the results in the table **Exposure_flood**.
- What can you conclude when you check the vulnerability values? (You can also order them from high to low, by selecting Column, sort, and select the appropriate column in descending order).
- IMPORTANT: DO NOT RUN THE SAME SCRIPT FOR VULNERABNILITY TWICE, AS INTERMEDIATE RESULTS ARE DELETED. YOU NEED TO RE-RUN THE SCRIPT FOR EXPOSURE BEFORE YOU CAN RUN THE VULNERABIKLITY SCRIPT AGAIN.

- Run also the other vulnerability scripts for Hyperconcentrated flows (HCF-vulnerability), landslides (landslide_vulnerability) and mudflows (mudflow_vulnerability). Check the results.

13.6 RISK ANALYSIS

In the risk analysis we are going to calculate 3 types of risk:

- **Individual risk** = the probability of being killed by one of the types of hazard by a person that lives in one of the buildings in the exposed area.
- **Societal risk** = the number of people that might be killed in the area as a consequence of the natural hazards, and the associated probabilities of these losses.
- **Economic risk** = the expected losses to buildings expressed in terms of economic values (Euros) and the probability of these losses.

13.7 INDIVIDUAL RISK

Risk to individuals can be calculated as:

$P_{LOL} = P_{(R)} * P_{(T:R)} * P_{(S:T)} * V_{(D:T)}$

In which :

P_{LOL} = individual risk to loss of life of an individual exposed to one of the hazards
$P_{(R)}$ = the annual probability of occurrence of the hazard, calculated as 1/return period
$P_{(T:R)}$ = the probability that a landslide reaches the element at risk. As the models used do not consider this probability, we take this as 1.
$P_{(S:T)}$ = the temporal spatial probability of the element at risk. In order word, what is the probability that the person is actually in the building when the hazard strikes. For example, we could consider that people are in the building for 40% of the time, so than this factor is 0.4. In the first run we use a factor of 1.
$V_{(D:T)}$ = the vulnerability of the person in relation to the intensity of the hazard. This we have evaluated in the previous section, and are the vulnerability values calculated before.

- Open the script **Risk_individual**. The key lines are indicated in the table below. Fill in the table the various parameters that have been used in this case.

	$P_{(R)}$	$P_{(T:R)}$	$P_{(S:T)}$	$V_{(D:T)}$
Risk_flood_020:=(1/20)*Vuln020				Vuln020
Risk_flood_100:=(1/100)*Vuln100				Vuln100
Risk_HCF:=(1/200)*0.5*Vuln				Vuln
Risk_landslide:=(4/80)*(1/10)*Vuln				Vuln
Risk_mudflow:=(1/200)*Vuln				Vuln

- Run the script **Risk_individual**, by clicking on the triangle icon. Check the results in the table Risk_individual.tbt
  - What can you conclude when you check the individual risk values?
  - Which hazard type results in the highest levels of individual risk?
  - If we consider that individual risk larger than 1.E-04 would be unacceptable, then how many buildings have an unacceptable risk level?

- IMPORTANT: YOU CAN RE-RUN THE SCRIPT FOR RISK_INDIVIDUAL AGAIN, BUT IT ONLY WORKS IF YOU HAVE RUN ALL EXPOSURE AND VULNERABILITY SCRIPTS BEFORE.

13.8 SOCIETAL RISK

Societal risk can be calculated as:

$P_{SOC} = P_{(R)} * (P_{(T:R)} * P_{(S:T)} * V_{(D:T)} * N_{(people)})$

In which :

P_{SOC} = societal risk to loss of life of all individuals exposed
$N_{(People)}$ = the number of people living in the building exposed to a certain level of hazard.

In this analysis we are only going to work with the risk that is associated with the same return period, by calculating the losses separately ($P_{(T:R)} * P_{(S:T)} * V_{(D:T)} * N_{(people)}$) for a given probability. We therefore only are going to look at the hyperconcentrated flows, mudflows and landslides.

- Open the script **Risk_societal**. The key lines are indicated in the table below. The same vulnerability values are used as in the individual risk calculation , but now we also use the column People from the table Buildings, that gie us the number of people per building. Fill in the table the various parameters that have been used in this case.

	$P_{(T:R)}$	$P_{(S:T)}$	$V_{(D:T)}$	
Risk_HCF:=0.5*Vuln*People			Vuln	People
Risk_landslide:=(4/10)*Vuln*People			Vuln	People
Risk_mudflow:=Vuln*People			Vuln	People

- Run the script **Risk_societal**, by clicking on the triangle icon. Check the results in the table Risk_societal.tbt
  - What can you conclude when you check the societal risk values?
  - Which hazard type results in the highest levels of societal risk?

13.9 ECONOMIC RISK

Economic risk can be calculated as:

$P_{eco} = P_{(R)} * (P_{(T:R)} * V_{(D:T)} * N_{(value)})$

In which :

P_{ECO} = economic risk expressed in monetary losses of all buildings exposed
$P_{(R)}$ = the annual probability of occurrence of the hazard, calculated as 1/return period.
$V_{(D:T)}$ = the vulnerability of the building in relation to the intensity of the hazard.
$N_{(value)}$ = the total economic value of buildings exposed to a certain level of hazard.

Also in this analysis we are only going to work with the risk that are associated with hyperconcentrated flows, mudflows and landslides.

- Open the script **Risk_economic**. Check the contents. Run the script and evaluate the results.

13.10 VISUALIZATION OF THE RESULTS AND DISCUSSION

In last part we are going to make a prioritization of the various parts of the area, in terms of their risk levels. The visualization of the three types of risk will be compared.
The individual risk can be visualized building by building and the societal and economic risk can also be analyzed per sector. We have a map with 6 sectors in the study area that are considered for implementing risk reduction measures. The question is: which sector would get the priority.

- Open the map DTM_shadow and add the map Sectors. Make this map transparent. Check the contents. Make a prioritization of the sectors in terms of their societal and economic risk.
- Open the map DTM_shadow and add the map Risk_Individual_classified (which was made as part of the individual risk analysis). Which areas have the highest individual risk?

Given the short time for this tutorial and the available data for hazard, elements at risk and vulnerability, a number of assumptions were made in this analysis, some of which are wrong.

- Think about some of the major limitations in this analysis. Separate them in terms of Hazard assessment (frequency, initiation, runout, different scenarios), elements at risk characterization, and vulnerability (method for vulnerability assessment, values used etc.)
- Considering that we are dealing with multi-hazards occurring in the same area, some of which are triggered by the same triggering events, are we allowed to consider them separately as we did here? How could we improve that?

13.11 REFERENCES

- Cascini, L., Ferlisi, S., Sorbino,G. and Cuomo, S. (2011). Report of the activities carried out by the research group of Unisa. Deliverable D2.11. QRA case studies at selected “hotspots”. SafeLand. Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies. 22 pages.