Tutorial on the use of GIS for landslide risk assessment

The case study of Monte Albino, Nocera Inferiore, Italy

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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. We have converted the data for an Open Source GIS software called ILWIS, developed by ITC, which can be downloaded from 52North (http://52north.org/communities/ilwis/download).

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

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.
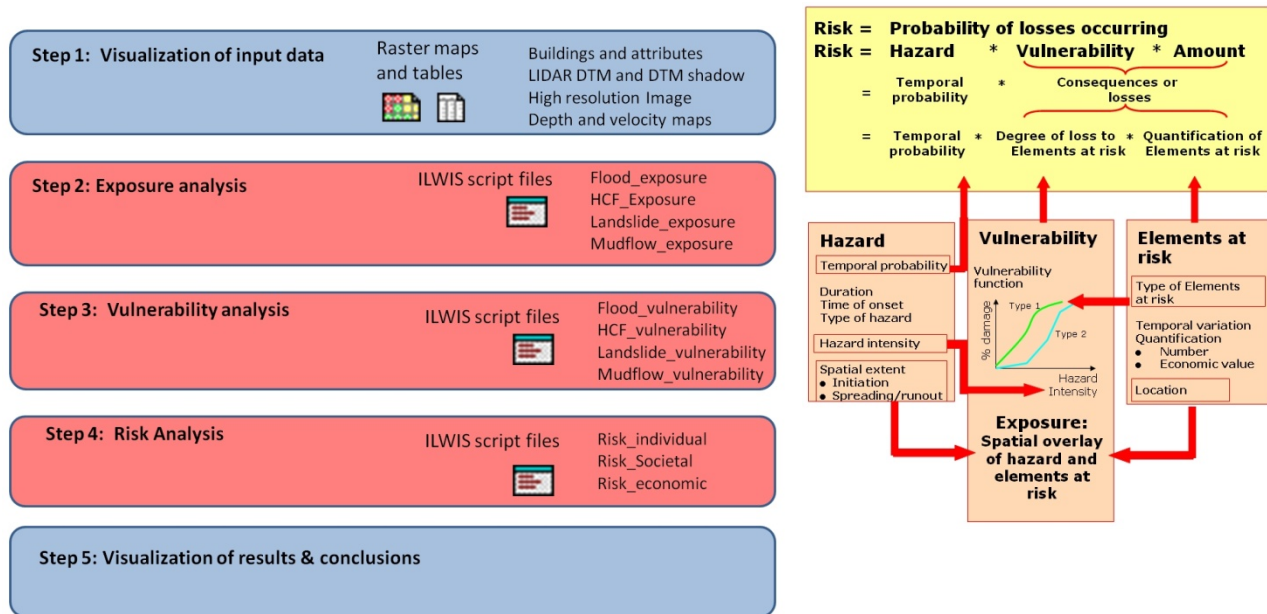

Software and data installation

We are using a beta version of ILWIS 3.08. It does not have a proper installer, just copy the ilwis folder from the zip (**n52_ilwis_v3_08_beta_1.zip**) to a directory on your harddisk (ILWIS308) . Make a short cut on the Desktop of the ILWIS icon. Create a directory \Nocera exercise and unzip the data files that you can find in the **exercise_nocera.ZIP** file. Open the ILWIS program and navigate to the directory \Nocera .

Step 1: 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.

- Open the ILWIS program and navigate to the directory \Nocera .

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.
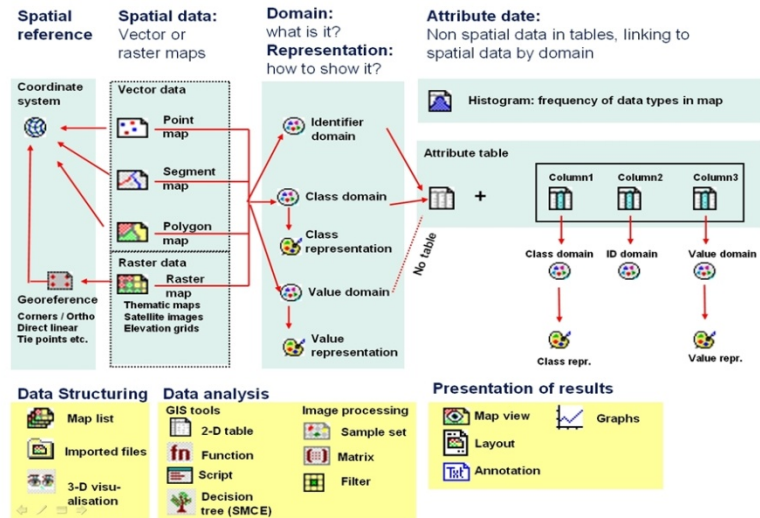
- Double click on the raster map **IMAGE** . You can zoom in on certain areas, and use the upper left icon to display the entire image.

This is a high resolution image of the study area. We can also display this image in 3-D so you have a better idea of the area.

- Click on the small plus left of the icon of the map **IMAGE** to expand. Expand the Global tools and select 3D. Right click on Display tools, and select 3-D properties. Expand the Display tools , and expand 3D properties. Double click on Data sources. Select the option Raster Map and select the raster map **DTM**. Select Apply. Select Scaling and use the scale bar to increase the Z-scaling.   You can rotate the image by keep Ctrl key pressed and moving with the mouse. Zoom in and out with Crtl and the mouse wheel. Rotate the image so you can appreciate the elevation differences. Close the window when ready.

We will now see some of the input data for the exercise. We will display the input data on top of a hillshading image of the area (called **DTM_shadow**). We first display the flood map as example

- Double click on the raster map **DTM_SHADOW** . Select the Add layer button (green plus) and add the map **Flood_depth_020y**. Expand the information for this map, and the Display tools. Double click on Tranparency and increase the transparency to 50%. Double click on Stretch and reduce 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.

- Move the Pixel Information window in the bottom left a bit up so there is room for more information. Right click in this 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.

Step 2: 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),

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.
    - o Which of the hazards has the largest number of exposed buildings?
    - o 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.
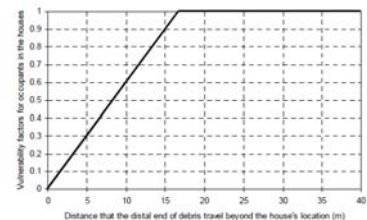
Step 3: Vulnerability analysis

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	
$h \geq 1$ and $v \geq 5$	0.1	$h \geq 1$ and $v \geq 5$	0.15	$h \geq 1$ and $v \geq 7$	1
$h \geq 1$ and $1 \leq v < 5$	0.05	$h \geq 1$ and $1 \leq v < 5$	0.1	$h \geq 1$ and $3 \leq v < 7$	0.8
$0.5 \leq h < 1$ and $v \geq 5$	0.05	$0.5 \leq h < 1$ and $v \geq 5$	0.1	$0.5 \leq h < 1$ and $v \geq 7$	0.8
$h \geq 1$ and $v < 1$	0.025	$h \geq 1$ and $v < 1$	0.08	$h \geq 1$ and $v < 3$	0.4
$0.5 \leq h < 1$ and $1 \leq v < 5$	0.025	$0.5 \leq h < 1$ and $1 \leq v < 5$	0.08	$0.5 \leq h < 1$ and $3 \leq v < 7$	0.4
$h < 0.5$ and $v \geq 5$	0.025	$h < 0.5$ and $v \geq 5$	0.08	$h < 0.5$ and $v \geq 7$	0.4
$0.5 \leq h < 1$ and $v < 1$	0.01	$0.5 \leq h < 1$ and $v < 1$	0.05	$0.5 \leq h < 1$ and $v < 3$	0.2
$h < 0.5$ and $1 \leq v < 5$	0.01	$h < 0.5$ and $1 \leq v < 5$	0.05	$h < 0.5$ and $3 \leq v < 7$ 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.

Step 4: 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.

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.

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?

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.

Step 5: 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?

Reference:
- 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.