

Exercise 06L: Landslide risk assesment

Expected time: 3 hours
 Data: data from subdirectory: Riskcity exercise/exercise06L/data
 Objectives: This exercise shows you a semi-quantitative method for landslide risk assessment, and intends to use landslides from different periods to calculate the temporal probability and convert susceptibility maps to hazard maps. These are then combined with elements at risk information to derive at risk maps.

Input data

In this exercise we will use the landslide **Susceptibility_map** that was generated using a statistical method in exercise 3.L. For the elements at risk we will use a map called **Building_map_1998** with the individual buildings and their characteristics. The map **Landslide_ID** is also required in order to convert the susceptibility map into a hazard map, by including the temporal landslide information.

Name	Type	Meaning
Elements at risk		
Building_map_1998	Raster	Map showing individual buildings.
Building_map_1998	Table	Table showing buildings characteristics: landuse, nr of floors, building type, area building, floor space (persons per day, persons per night, size class – not used in this exercise).
Landslide data		
Landslide_ID	Raster	Points within each of the interpreted landslides with associated attribute table
Landslide_ID	Table	Attribute table with information on the landslides in the area.
Susceptibility	Raster	Landslide susceptibility map made using a statistical method.
Other data		
High_res_image	Raster	High resolution image of the study area.

- General Risk formula:**

$$\text{Risk} = H * V * A$$

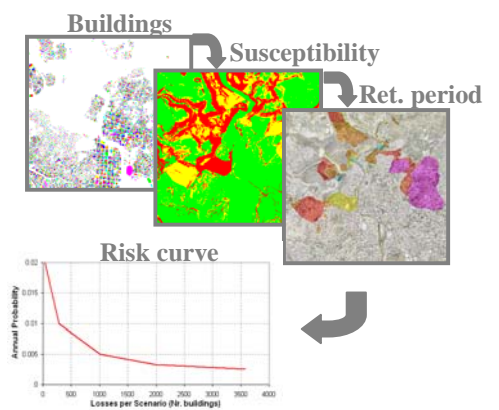
H= Hazard
 V= Vulnerability
 A= Amount of Elements at risk

- Landslide Risk Formula:**

$$\text{Risk} = P_T * P_S * V * A$$

P_T=Temporal Probability
 P_S=Spatial Probability
 V= Vulnerability
 A= Amount of Elements at risk

The first formula in the box on the left expresses the general risk related to a natural (or man induced) hazard. The first term "Hazard" expresses the temporal occurrence probability of the hazardous event. When we can exactly define the spatial occurrence of the hazard, H expresses the spatial occurrence of the hazard, H expresses the temporal probability (annual probability/return period) only. This is the case for flood hazard where a particular site is known to be flooded based on the results of a flood modeling study. A certain element at risk is in the hazard zone or not; therefore the spatial probability is equal to 1. For other hazards, like landslides (or forest fires), we don't know exactly where the hazardous event will occur; therefore we need to introduce in the equation the spatial probability. In this case, the formula has to include the spatial and temporal probability as indicated in the second formula in the left box. For a more in depth discussion see chapter 6 of the guidebook. For this exercise, the spatial probability is calculated from the **Susceptibility map**, while the information about the return periods for the surveyed landslides provides the temporal probability. This information is stored in the **Landslide_ID map**. In the first part of the exercise we will follow a semi-quantitative approach for landslide risk assessment. This focuses on the "Amount" part of the formula. We combine the susceptibility zones with the different building types, and calculate the number of houses and people in High, Moderate and Low susceptibility zones.



The second part then continues with a quantitative approach for landslide risk assessment. We will combine the susceptibility with the information related to the return period of the surveyed landslides, in order to calculate the temporal probability. Moreover vulnerability values will be estimated according to the building type and the floor space. Vulnerability should be dependant on the characteristics of the elements at risk and on the hazard characteristics. In other words, a building is more or less vulnerable according to its material and its structure, and depending on the type and dimension of the landslide. Here, only the characteristics of the elements at risk are considered, due to the complexity of the vulnerability evaluation. We will then plot the Temporal Probability (P_T) against the spatial probability multiplied with the losses ($P_S \cdot V \cdot A$).

Calculate the number of buildings in high, moderate and low landslide susceptibility classes

The first step is to calculate the amount of buildings present in each of the three susceptibility classes (Low, Moderate, and High). We will calculate the amount of buildings per each susceptibility class according to the building types.



- Select *Operations / Raster Operations / Cross*. Cross the raster map **Building_map_1998** with the raster map **Susceptibility**. Call the cross table **Building_susceptibility**.
- Open the new table and check the content; you should see 4 columns, what does the column "Area" represent? In the column **Building_map_1998** we can observe that some buildings have more than one column; why?
- Identify which is the predominant susceptibility class for each building; go to *columns / aggregation* and chose *column: Susceptibility; function: predominant; group by: Building_map_1998; weight: Area*. Call the new column: **Susceptibility_per_building**. What does this operation calculate?
- Open the table **Building_map_1998** and join the column we created. Go to *Columns / Join*; chose the table **Building_susceptibility** and the column **Susceptibility_per_building**; call the new column **Susceptibility**.
- To calculate the amount of buildings with different building types in each class we need a further operation. In the command line of the table **Building_map_1998** type the following line:

```
combine = code(building_type) + "_" + code(susceptibility)
```

IMPORTANT: this command creates a column with a combination of the code of the domain **Building_type** and the code of the domain **Susceptibility**. Carefully check that both the two domains contain a code for each class; otherwise add them (In the susceptibility domain add the following codes if not present; High class: **H**; Moderate class: **M**; Low class: **L**). Check the column **Combine**. What do the acronyms stand for?

- We want to store the results in a separate table. In the table **Building_map_1998** select the column **Combine** and right click on its header; open the option *properties* and chose *create domain from string of column*. Call the new domain **Buildtype_susceptibility**. In the main window right click on the new domain and chose *Create table*. Call the new table **Buildtype_susceptibility**. In the table **Building_map_1998** go to *Columns / Aggregation* and chose *column: Combine; function: count; group by: Combine*; store the new column in the output table **Buildtype_susceptibility** and call the column **Nr_buildings**. This new column shows the number of buildings for each susceptibility class according to their type.

Fill the table below with the results stored in the table **Buildtype_susceptibility**. You can create your own table in Excel and calculate all the required values.

		Susceptibility classes						Total per type
		Low	% of building type	Mod	% of building type	High	% of building type	
Building Types	Adobe	1288	45%	1187	41%	410	14%	2885
	Wood and others							
	Fieldstone							
	Brick with mud							
	Brick with cement							
	Reinforced concrete							
	Total per class		19717					28038
Perc. of total		70%						

Once the table is filled you can explore the distribution of the buildings among the three susceptibility classes for each building type. Please answer the following questions.

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- Within the “brick with cement” type, how are the buildings distributed among the susceptibility classes? Give the percentages.
 Low _____ Moderate _____ High _____
 Within the “wood and other scrap materials” type, how are the buildings distributed among the susceptibility classes? Give the percentages
 Low _____ Moderate _____ High _____
 Comment the two different patterns and try to give your own explanation to justify the differences.
- For each of the susceptibility classes, extract the building type with the highest percentage; try to find out what is the most common landuse for the chosen building types (go to building_map_1998 and sort it by building_type).
 Low: _____ Landuse: _____
 Moderate: _____ Landuse: _____
 High: _____ Landuse: _____
 Why are those landuse classes predominant in those susceptibility classes?
- Try to show the results stored in the above table through a cumulative histogram in Excel and comment it. Check the example below.

Building Type	Low susceptibility (%)	Moderate susceptibility (%)	High susceptibility (%)
AD	45%	41%	14%
WO	41%	45%	14%
FI	41%	45%	14%
B_M	41%	45%	14%
B_C	41%	45%	14%
RCC	41%	45%	14%

We can also display the results in a map that shows the susceptibility class of each building.



- Create an attribute map from the **Building_map_1998** using the column **Susceptibility**; call the new map **Building_susceptibility**; in the main ILWIS menu, go to *Operations / Raster operations / Attribute map*; chose *Raster map: Building_map_1998; Table: Building_map_1998; Column: Susceptibility*.

This output can be a good example of a simple landslides risk map used by local authorities to inform the population.

Quantitative calculation of annual risk and generation of a risk curve for landslides.

Up to now we calculated only the number of buildings in the different susceptibility classes. Referring to the general Risk formula, the number of buildings represents the Amount (A). Now we have to extract the Hazard (H) and the Vulnerability (V) to be able to calculate the Risk.

1. How much percentage of the high, moderate and low hazard classes may be affected by landslides?
2. In which period will these landslides occur?
3. What is the vulnerability to landslides for each building type?

From susceptibility to hazard

As we stated in the introduction of the exercise, in landslide risk assessment the Hazard occurrence probability is expressed by the Spatial and the Temporal probability. Therefore in the general formula:

$$\text{Risk} = \text{Hazard} * \text{Vulnerability} * \text{Amount}$$

The hazard is expressed as follows:

$$\text{Hazard} = \text{Temporal probability} * \text{Spatial probability}$$

In order to calculate the hazard probability, we need to have both the components:

- The **temporal probability** that landslides may occur due to a triggering event. Here we will link the return period of the triggering event with the landslides that are caused by it. We have differentiated return periods of: 50, 100, 200, 300 and 400 years. The required data are stored in the **Landslide_ID** map.
- The **spatial probability** that a particular area would be affected by landslides of the given temporal probability. This is calculated as the landslide density within the landslide susceptibility class.

If the indication of the high, moderate and low areas susceptibility is correct, different landslide events with different return periods will give different distributions of landslides in these classes. The probability can be estimated by multiplying the temporal probability (1/return period for annual probability) with the spatial probability (= what is the chance that a building is affected).

- Make an attribute map of the column **ReturnPeriod** of table **Landslide_ID** using the map **Landslide_ID**. Name the map: **Landslide_RP**
- Check the contents of the maps **Landslide_RP** and **Susceptibility**.
- Cross the map **Susceptibility** with the map **Landslide_RP**. Go to *Raster Operations / Cross*; Select the option do not ignore undefined values. Create the output table: **Hazard_RP**.
- Calculate the area of each hazard class (use aggregation function) and write it in an Excel file with the same structure as the table below. Open the table **Hazard_RP**, go to *column, aggregation*, and select the column **area** and the function **sum**. Group by **Susceptibility**. Call the output column **class_area**.
- In the table **Hazard_RP**, type the following formulas:
Area_low:=iff(susceptibility="low",area,0)
Area_moderate:=iff(susceptibility="moderate",area,0)
Area_high:=iff(susceptibility="high",area,0)
- Go to *column, aggregation*, and select the column **area_low**, the function **sum**, group by **Landslide_RP**, store the result in the table **Landslide_probability** and call the new column **Landslide_area_low**. Do the same for the field **area_high** and **area_moderate** and store the result in the table **Landslide_probability**.

The hazard is calculated as the multiplication of temporal probability and spatial probability. So this is the annual probability that a given location (building) will be hit by a landslide within a certain hazard class. The required data are stored in the tables **Hazard_RP** and **Landslide_probability**. Follow the instructions below to fill the table as in the lines already completed. It is suggested to build the table in an Excel sheet to simplify the calculations. Use scientific annotation with 3 decimals.

Hazard		1/50	1/100	1/200	1/300	1/400
High	Landslide area	4.658E+04	3.759E+05	2.319E+05	1.910E+05	1.078E+05
	Cumulative landslide area	4.658E+04	4.225E+05	6.543E+05	8.453E+05	9.531E+05
	Class area	2.567E+06	2.567E+06	2.567E+06	2.567E+06	2.567E+06
	Spatial probability P _s (density)	1.815E-02				
	Temporal Probability P _T	2.000E-02				
	Hazard: P _T *P _s	3.620E-04				
Moderate	Landslide area	4.000E+00				
	Cumulative landslide area	4.000E+00				
	Class area	3.049E+06				
	Spatial probability P _s (density)	1.300E-06				
	Temporal Probability	2.000E-02				
	Hazard: P _T *P _s	2.600E-08				
Low	Landslide area	5.000E+00				
	Cumulative landslide area	5.000E+00				
	Class area	8.384E+06				
	Spatial probability P _s (density)	5.960E-07				
	Temporal Probability	2.000E-02				
	Hazard: P _T *P _s	1.190E-08				

- Fill the table with the data calculated. The columns **Landslide_area_low**, **Landslide_area_moderate**, **Landslide_area_high**, in the table **Landslide_probability** provide the values of the *landslide area* in each susceptibility class. The values of the *class area* are stored in the table **Hazard_RP**, column **Class_area**.
- Calculate the cumulative landslide area (see example in the table) as the **assumption is that events with a larger return period will also trigger those landslides that would be triggered by events from smaller return periods.**
- The spatial probability is expressed as the density of the landslides in the susceptibility class: therefore it is given by the formula (in the Excel sheet):
Spatial_probability = Cumulative_landslide_area / Class_area
- Now calculate the temporal probability per hazard class and per return period, and write the results in the table. Temporal probability = annual probability = 1/ return period.
- Calculate the hazard per hazard class and per return period, and write the results in the table: $H = P_T * P_S$

The temporal and spatial probabilities express the chance of occurrence of a landslide at each location. The first step in the loss estimation will be calculation of the **amount of losses for each scenario** (return period). To do this we will use only the information related to the spatial probability. The temporal probability will be introduced later when the annual risk will be calculated in the risk curve.

- Right click on the domain Susceptibility and create a table **Spatial_probability**. Create five columns as indicated below. Use value range from 0 to 1, and a precision of 0.000000001 with 9 decimals. Fill the table below with the values of the spatial probability.
- Which hazard class has the highest spatial probability values? Is it the expected result?
- Try to explain why this class has the highest spatial probability of occurrence (Suggestion: explore together the **Susceptibility** map and the **Landslide_RP** map; think about how the susceptibility map was created).

		Spatial probability				
		Spat_prob_50y	Spat_prob_100y	Spat_prob_200y	Spat_prob_300y	Spat_prob_400y
Hazard Classes	HIGH	1.815E-02				
	MOD	1.300E-06				
	LOW	5.960E-07				

Estimating Vulnerability

Estimating landslide vulnerability is very complex. It requires knowledge on the building types and on the expected landslide volumes and velocities. These are difficult to estimate. Therefore, in many studies landslide vulnerability of buildings is simply taken as 1, assuming complete destruction of the elements at risk. In this case we don't have enough information about the landslides parameters (type, velocity, volume etc.). Therefore we will make use of a vulnerability scale based only on the building characteristics: type of construction and dimension of the building.

Of course one can debate the correctness of this. It is also possible to take into account the landslide volumes from the landslide map as indication of the possible landslide magnitudes, but that would make the exercise too complicated. Therefore we will limit the vulnerability assessment to the building characteristics mentioned above. The vulnerability calculation is carried out by expert engineers on the basis of physical studies on buildings behavior and on historic data related to damages caused by landslides. In the table below the damage percentages are given as function of the building type and building size.

VULNERABILITY				
Building type: Adobe				
Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	1.00	1.00
Building type: Wood and other poor materials				
Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	0.90	0.80
Building type: Fieldstone				
Very small	Small	Medium	Large	Very large
1.00	1.00	1.00	0.90	0.90
Building type: Brick with mud				
Very small	Small	Medium	Large	Very large
1.00	1.00	0.90	0.80	0.70
Building type: Brick with cement				
Very small	Small	Medium	Large	Very large
1.00	0.90	0.80	0.60	0.50
Building type: Reinforced concrete				
Very small	Small	Medium	Large	Very large
0.60	0.50	0.40	0.35	0.30

The strength of a building is supposed to depend not only on its area but also on the number of floors: a building in brick with cement with 3 floors has a stronger structure than a 1 storey building with the same characteristics. Therefore, the buildings have to be classified in relation to their construction types and their dimension. We already have the building type classification but we need to classify them according to their dimension. We will define five classes (very small, small, medium, large, and very large). To define the boundaries of the five dimension classes (from *very small* to *very large*) we will use the overall building floorspace (area * Nr floors).

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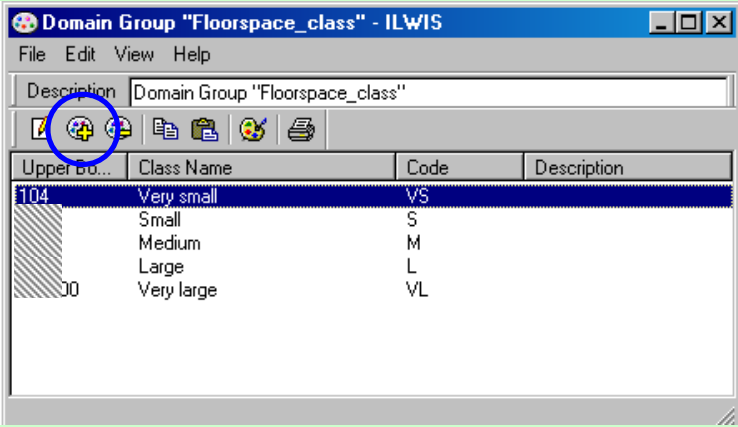
- Create an attribute map from **Building_map_1998** using the column **Floorspace** and call it **Floorspace_map**. Build the histogram of the map: right-click on the map go to *Statistics / Histogram*.
- Open the histogram and study it. What is the meaning of the columns **Value**, **Npixpct** and **Npixcum**?
- In order to define the boundaries of the floor space classes we will create a column with the cumulative percentage of the floor space. Visualize the command line in the histogram (if not already visible: select *View / Command line*). Type the following command:

$$\text{perc_cum} = \text{npixcum} / 3154801 * 100$$

What does the large number refer to?
- We can divide the floor space into five classes according to their cumulative percentages. Fill the table with the correct values.

Class name	Cum. percentage	Floor space value (upper boundary)
Very small	20%	104
Small	40%	
Medium	60%	
Large	80%	
Very large	100%	

- Create a new domain, in the main IWIS menu go to *File / Create / Domain*; chose *Class / Group* and call it **Floorspace_class**. Fill the window using the values store in the table above as shown in the figure below; to add a new class in the domain, click the icon with the blue circle.



- Open the **Building_map_1998** table and type the following command in the command line:

$$\text{Floorspace_class} = \text{clfy}(\text{Floorspace}, \text{Floorspace_class})$$

What does the function **clfy** calculate? What does the new column contain?

We created a classification for the floor space; now we can apply the vulnerability values. To do this we have to create a 2D table where to store those values.

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- In the main ILWIS menu, go to *File / Create / 2D Table* and choose as *Table Name: Vulnerability_building* *Primary domain: Building_type* and *Secondary domain: Floorspace_class*; *Minimum: 0*; *Maximum: 1* and *Precision: 0.1*. Open the table and fill it with the values reported in the vulnerability table shown above.
- Open the table **Building_map_1998** and type the following command in the command line:
Vulnerability_building = vulnerability_building[Building_type, Floorspace_class]
- Check the content of the new column and explain the performed operation.

We just created a column with the vulnerability value for each building

Estimating losses and generating the Risk Curve

Now that we have calculated all components of the landslide risk we can start to calculate the risk itself. The calculation will be done in the table **Building_map_1998**. We will calculate the losses for the 50 year return period scenario. The first step is to assign the correct spatial probability (P_s) to each building based on its susceptibility class. We need the P_s values for the 50 years scenario stored in the table **Spatial Probability** we filled before in this exercise. (High: 0.01815; Moderate: 0.0000013; Low: 0.000000596, the values can be slightly different if you have used other precisions)

IMPORTANT!

We are dealing with very small numbers. When you create a new column, remember to set the precision to 9 decimal numbers and the number of decimals to 9 in the table properties window; otherwise you will run into calculation errors.

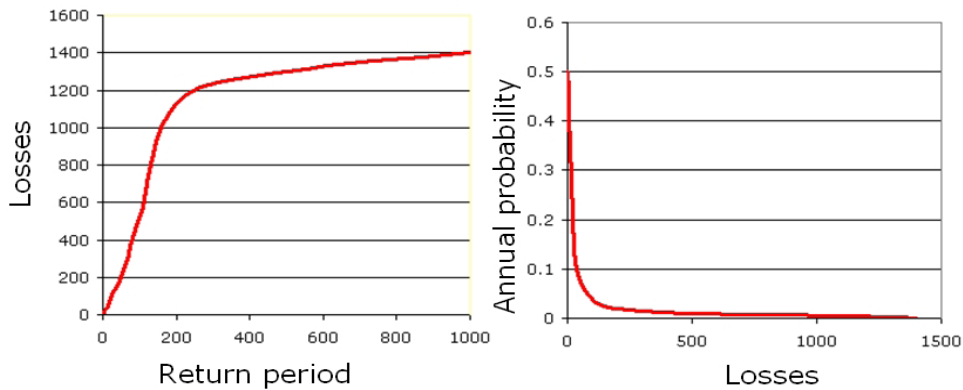
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- In the table **Building_map_1998**, join with the table **Spatial_probability** and read in the following column: **Spat_prob_50y**. Use value range from 0 to 1, and a precision of 0.000000001 with 9 decimals.
- To extract the total losses for the 50 years return period scenario, we have to multiply the spatial probability by the vulnerability for each building and sum up the losses.
- Multiply the two columns through the command:
Losses_50y:= Spat_prob_50y*vulnerability_building
- Show the statistic pane in the table and read the sum of the new column. It represents the total losses for the 50 years return period scenario!
- Apply the same methodology to the 100, 200, 300, 400 years return periods scenarios and calculate the total losses for each of them.
- In the calculations above we apparently don't take into account the **Amount** any more. Can you explain why there is no need here to use the amount of buildings calculated in the first part of the exercise? In which units are the losses indicated here?

We store the results in the table below for each of the scenarios (create your own table in the same Excel sheet).

Return Period	Temporal probability	Losses	Specific risk
50	0.02	31	0.62
100	0.01		
200	0.005		
300	0.00333		
400	0.0025		
Total risk (buildings)			

The risk can be represented as a curve, in which all scenarios are plotted with their return periods or probability and associated losses. Such a risk curve is also called the Loss Exceedance Curve (LEC). The left graph has the advantage that it is better visible which return periods have the largest contribution to losses. The right curve can be used directly to calculate the Average Annual Losses (AAL). This is done by calculating the area under the curve (also Guide Book, session 6.5.5).



Two ways to represent a risk curve. Left: Plotting losses against return period. Right: plotting losses against annual probability.



- Create the Risk curves, and plot the values for the 5 return period scenarios in the graph. Display the risk curve in the two ways shown in the figure. Store it in the same Excel sheet and compare your results with the ones in Blackboard.



- How to evaluate this risk? Is it high? How would it compare with other hazard types?
- Display the results also in the map by showing the attribute **Losses_50y** with the map Building_map_1998. Where are the zones with the highest individual risk levels?

Conclusion: if you look at the formula $Risk = PT \cdot PS \cdot V \cdot A$ and if we want to calculate the losses for individual buildings, it becomes clear that the spatial probability that a landslide will occur at the location of a building is the most crucial aspect. This value was derived from landslide density within the susceptibility classes. So the better one can define the susceptibility classes, the higher the success rate will be and the higher the spatial probabilities will be.