

9. Statistical landslide hazard assessment

In this exercise we will generate a landslide susceptibility map, using a basic, but useful, statistical method, called hazard index method. This method is based upon the following formula:

$$\ln W_i = \ln \left(\frac{\text{Densclas}}{\text{Densmap}} \right) = \ln \left(\frac{\frac{\text{Area}(S_i)}{\text{Area}(N_i)}}{\frac{\sum \text{Area}(S_i)}{\sum \text{Area}(N_i)}} \right) \quad [1]$$

where,

W_i = the weight given to a certain parameter class (e.g. a rock type, or a slope class).

Densclas = the landslide density within the parameter class.

Densmap = the landslide density within the entire map.

Area(S_i) = area, which contain landslides, in a certain parameter class.

Area(N_i) = total area in a certain parameter class.

The method is based on map crossing of a landslide map with a certain parameter map. The map crossing results in a cross table, which can be used to calculate the density of landslides per parameter class. A standardization of these density values can be obtained by relating them to the overall density in the entire area. The relation can be done by division or by subtraction. In this exercise the landslide density per class is divided by the landslide density in the entire map. The natural logarithm is used to give negative weights when the landslide density is lower than normal, and positive when it is higher than normal. By combining two or more maps of weight-values a hazard map can be created. The hazard map value is obtained by simply adding the separate weight-values. An overview of the method is shown in the next figure.

Data needed:

- A landslide map: **Slides**
- A slope map, which was made from the DTM based on contour interpolation. Map **Slope** (raster)
- A Lithological map for the study area. Map: **Lithology** (Polygons + table).

9.1 Getting started

In this exercise the landslide hazard map is made by using only two parameter maps: **Lithology** (geology) and **Slope** (slope map in degrees). The landslides are stored in the map **Slides**

Bivariate statistical analysis

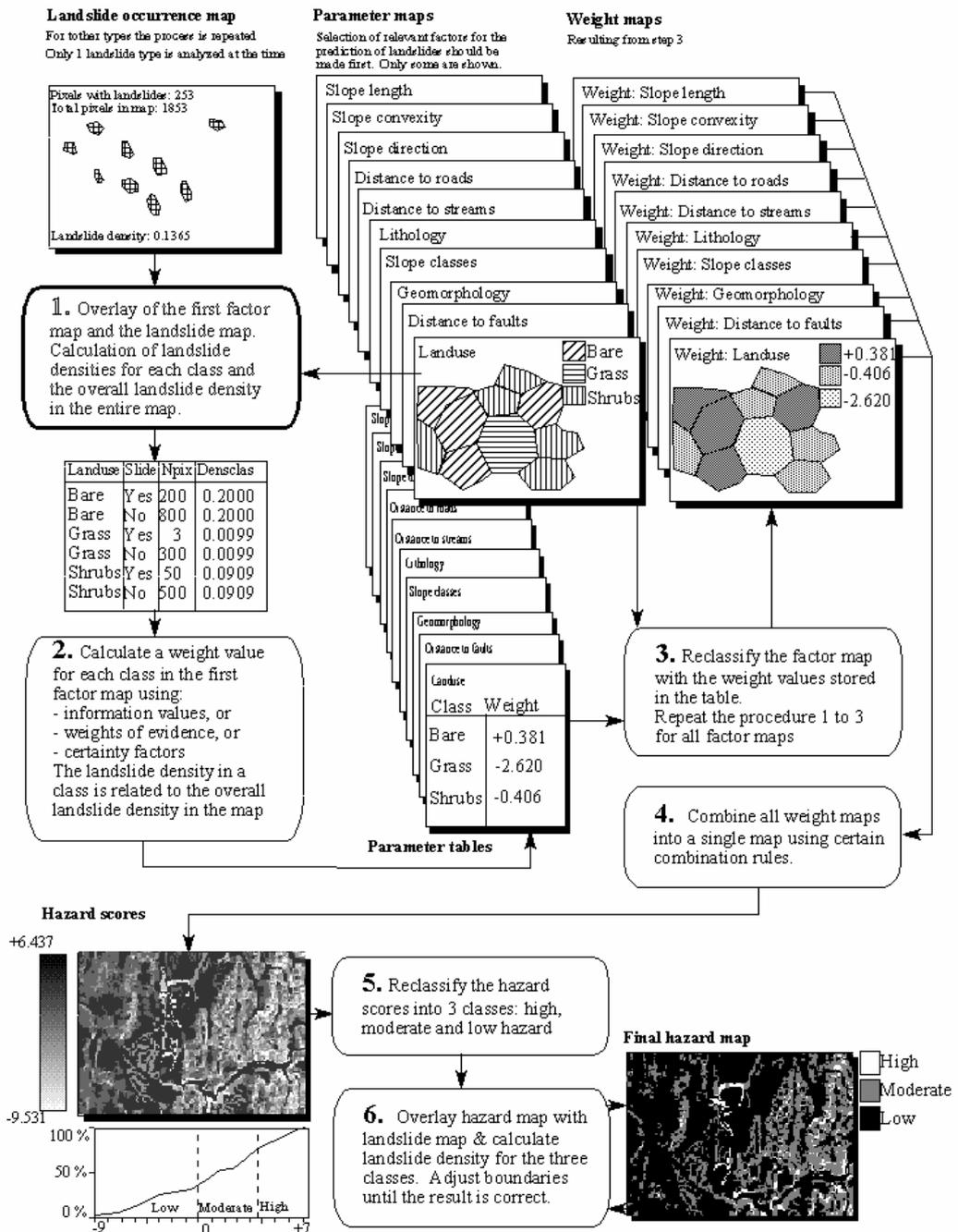


Figure 1: Simplified flowchart for bivariate statistical analysis. In this exercise only 2 input maps are used



- Open the map **High_res_image** and add the layer **Slides**. Click OK in the Display Options dialog box. The map is displayed.

Along side the landslide map you also have two parameter maps: **Lithology** (geological units) and **Slope** (slope angles).



- Open the map **Lithology** and consult the information from the map and the accompanying table.
- Add the maps **Lithology** and **Slope** to the pixel information window. When you move through the map you can simultaneously read the information from all three maps and their tables.
- Also open the map **Slope** and look at the content. The map **Slope** still needs to be classified into classes. Make a class (group) domain **Slopecl**, and add the slope classes you want to differentiate. You can make classes of 10 degree each.
- Select from the main window: *Operations / Image Processing / Slicing*. Select the raster map **Slope**, and the domain **Slopecl**. Name the output map **Slopecl**.
- Close the map windows and the Pixel information window
- Before you can use the maps in the analysis, you need to rasterize the maps **Slides** and **Lithology**. Select from the main window *Operations / Rasterize / Polygon to Raster*. Select the polygon map: **Slides**, the georeference **Somewhere** and the output raster map: **Slides**. Do the same for the polygon map **Lithology**. Check the results

So far you have only been looking at the content of the maps. You will now start with the actual analysis. A statistical analysis should be done using landslides with same characteristics. That is why we will separate the fossil landslides from the recent ones. We do that using a map calculation formula.



- We are going to use only the classes **Br** (body of recent landslides) and **Sr** (scarp of recent landslides). See the domain **Slides** for all codes and names. We make now a map in which these will have a value 1 and the rest (including the no-landslide areas) a value of 0. Type the following formula on the command line:
Active:=iff(isundef(slides),0,iff((slides="br")or(Slides="sr"),1,0))
- Meaning: if the map **Slides** has undefined values (? In the non-landslide areas) then the result is 0. If the map **Slides** has the codes **Br** or **Sr**, than we assign a value of 1. For the other landslides we assign a value of 0.
- The output map **Active** has a value domain, with minimum 0, maximum 1 and precision 1.



- **Additional exercise:**
- By the way, if you want to know how the slope map as made. Here is the procedure:
- 1. Apply filter operation on the map **Topo_dem**. First **DFDX** filter (name map also **DFDX**) and then **DFDY** filter (resulting in **DFDY** map).
- 2. Type on the command line:
$$\text{SLOPEPCT} = 100 * \text{HYP}(\text{DFDX}, \text{DFDY}) \text{ and}$$
$$\text{SLOPE} = \text{RADDEG}(\text{ATAN}(\text{SLOPEPCT}/100))$$
- Also make a slope map of the **Lidar_dem**. Check the differences.

9.2 Crossing the parameter maps with the landslide map

The landslide occurrence map, showing only the recent landslides (**Active**) can be crossed with the parameter maps. In this case the two maps **Slopecl** and **Lithology** are selected as examples. Of course in real applications many more parameter maps should be evaluated. First the map crossings between the occurrence map and the two parameter maps have to be carried out.



- Select from the main ILWIS menu the options: Operations, Raster operations, Cross.
- Select the map **Slopecl** as the first map, the map **Active** as the second map, and call the output table **Actslope**. (Ignoring the undefined values has no effects, as both maps don't have undefined values). Click **Show** and **OK**. Now the crossing of the two maps takes place.
- Have a look at the resulting cross table. As you can see this table contains the combinations of the classes from the map **Slopecl** and the two types from the map **Active**.
- Repeat the procedure for the crossing of the maps **Lithology** and **Active**. Name the output cross-table **ActLithology**.

Now the amount of pixels with different landslide activities in each slope class and each geological unit, has been calculated, the landslide densities can be calculated.

9.3 Calculating landslide densities

After crossing the maps, the next step is to calculate density values. The cross-table includes the columns that will be calculated during this exercise. Each of the calculation steps is indicated below.



- Make sure that the cross-table **Actslope** is active.
Step 1: Create a column in which only the active landslide are indicated by typing the following formula on the command line of

the table window:

$\text{AreaAct} = \text{iff}(\text{Active} = 1, \text{area}, 0)$ ↓

You do this in order to calculate for each slope class the area with only active landslides.

- **Step 2:** Calculate the total area in each slope class.
Select from the table menu: **Columns, Aggregation**.
Select the column: **Area**. Select the function **Sum**. Select **group by** column **Slopecl**. Deselect the box **Output Table**, and enter the output column **Areasloptot**. Press OK. Select a precision of 1.0.
- **Step 3:** Calculate the area with active landslides in each slope class.
Again select from the table menu: **Column, Aggregation**.
Select the column: **AreaAct**, Select the function **Sum**, select **Group by** column **Slopecl**. Deselect the box **Output Table**, and enter the output column: **Areaslopeact**. Press OK. Select a precision of 1.0.
- **Step 4:** calculate the total area in the map .
Again select from the table menu: **Columns, Aggregation**.
Select the column: **Area**. Select the function **Sum**. Deselect the box **group by**. Deselect the box **Output table**, and enter the output column: **Areamaptot**. Press OK. Select a precision of 1 . 0.
- **Step 5:** The next step is to calculate the total area with landslides in the map. Again select from the table menu: **Columns, Aggregation**.
Select the column: **AreaAct**. Select the function **Sum**. Deselect the box **group by**. Deselect the box **Output Table**, and enter the output column: **Areamapact**. Press OK. Select a step size of 1 . 0.
- **Step 6:** Calculate the landslide density per slope class
Type:
 $\text{Densclas} = \text{Areaslopeact} / \text{Areasloptot}$ ↓
Select a precision of 0.0001.
- **Step 7:** Calculate the landslide density for the entire map.
Type:
 $\text{Densmap} = \text{Areamapact} / \text{Areamaptot}$ ↓
Select a precision of 0.0001.

The result will look like below:

	Active	NPix	Area	AreaAct	Areasloptot	Areaslopeact	Areamaptot	Areamapact	Densclas	Densmap
0-10 degrees	0	6722769	6722769	0	6737909	15140	14000000	225189	0.0022	0.0161
0-10 degrees	1	15140	15140	15140	6737909	15140	14000000	225189	0.0022	0.0161
10-20 degrees	0	3673980	3673980	0	3703788	29808	14000000	225189	0.0080	0.0161
10-20 degrees	1	29808	29808	29808	3703788	29808	14000000	225189	0.0080	0.0161
20-30 degrees	0	1851024	1851024	0	1899509	48485	14000000	225189	0.0255	0.0161
20-30 degrees	1	48485	48485	48485	1899509	48485	14000000	225189	0.0255	0.0161
30-40 degrees	0	1038726	1038726	0	1100738	62012	14000000	225189	0.0563	0.0161
30-40 degrees	1	62012	62012	62012	1100738	62012	14000000	225189	0.0563	0.0161
40-50 degrees	0	355591	355591	0	399912	44321	14000000	225189	0.1108	0.0161
40-50 degrees	1	44321	44321	44321	399912	44321	14000000	225189	0.1108	0.0161
50-90 degrees	0	132721	132721	0	158144	25423	14000000	225189	0.1608	0.0161
50-90 degrees	1	25423	25423	25423	158144	25423	14000000	225189	0.1608	0.0161

Table 2.1: Cross table and calculated columns

Now you have calculated all the required densities for the map slope.



- Repeat the procedure for the cross-table `ActLithology`. You don't have to calculate the density in the map anymore, since it is the same for both maps.

9.4 Calculating weight values

The final weight-values are calculated by taking the natural logarithm of the density in the class, divided by the density in the map. With this calculation we find that the density in the entire map = $225189 / 14000000 = 0.0161$

Previously the calculation was done on the cross-table for the maps **Slopec1** and **Active**. As you could see from the table 2.1, this results in many redundant values, since you only want to calculate the densities and the weights for each slope class. The result should look like table 2.2 instead, where each slope class occupies only one record. That is why you will work now with the attribute table connected to the map **Slopec1** and use table joining combined with aggregation to obtain the data from the cross table.

	Areasloptot	Areaslopeact	Areamaptot	Areamapact	Densclas	Densmap	Dclas	Weight
0-10 degrees	6737909	15140	14000000	225189	0.0022	0.0161	0.00220	-1.9904
10-20 degrees	3703788	29808	14000000	225189	0.0080	0.0161	0.00800	-0.6994
20-30 degrees	1899509	48485	14000000	225189	0.0255	0.0161	0.02550	0.4599
30-40 degrees	1100738	62012	14000000	225189	0.0563	0.0161	0.05630	1.2519
40-50 degrees	399912	44321	14000000	225189	0.1108	0.0161	0.11080	1.9289
50-90 degrees	158144	25423	14000000	225189	0.1608	0.0161	0.16080	2.3013

Table 5.3: Data stored in the attribute table.



- Create a table for the domain **Slopec1**. This table contains no additional columns, except the column with the domain. Repeat the procedure from above, but now with table joining.
- **Step 1:** Calculate the total area in each slope class. Select **Columns, Join**. Select table **Actslope**. Select column: **Area**. Select function **Sum**. Select group by column **Slopec1**. Select output column **Areasloptot**. Press **OK**.
- **Step 2:** Calculate the area with active landslides in each slope class. Select **Columns, Join**. Select table: **Actslope**. Select column **Areaact**. Select function **Sum**. Select group by column **Slopec1**. Select output column **Areaslopeact**. Press **OK**.
- **Step 3:** With both columns, you can calculate the landslide density in each slope class with the formula:

$$\text{Densclas} := \text{Areaslopeact} / \text{Areasloptot} \downarrow$$
 Select a precision of 0.0001.
- If you look at the result, some classes have a density of 0. This should be adjusted, since the calculation of the weights is not possible. To adjust type the following formula:

$$\text{Dclas} := \text{iff}(\text{Densclas} = 0, 0.0001, \text{Densclas}) \downarrow$$
- The final weight can now be calculated with the formula:

$$\text{Weight} := \ln(\text{Dclas} / 0.0161) \downarrow$$
- Close the table.

Now you have calculated the weights for the map **Slopec1**.



- Repeat the procedure for the table of the map **Lithology**.

9.5 Creating the weight maps

The weights from the table can now be used to renumber the maps.



- Select from the main ILWIS menu: Operations, Raster operations, Attribute map. Select raster map **Slopec1**. Select attribute **Weight**. Select output raster map **Wslopec1**. Press OK.
- Display the resulting map **Wslopec1**. Stretch between -2.5 and +2.5
- Use the same procedure the other parameter map **Lithology**. The resulting map should be called: **WLithology**.
- The weights for the two maps can be added with the formula:

$$\text{Weight} = \text{Wslopec1} + \text{WLithology}$$
- Display the map **Weight** and use the pixel information window in order to read the information from the maps **Slopec1**, **Wslopec1**, **Lithology**, **WLithology** and **Weight**.

9.6 Classifying the Weight map into the final hazard map

The map **Weight** has many values, and cannot be presented as it is as a qualitative hazard (susceptibility) map. In order to do so we first need to classify this map in a small number of units.



- Calculate the histogram of the map **Weight** and select the boundary values for three classes: Low hazard, Moderate hazard, and High hazard.
- Create a new domain: **Hazard**. By selecting: File, Create, Create domain. The domain should be a **Class** and tick on **Group**. Now enter the names and the boundary values of the different classes in the domain. When you are ready, close the domain.
- The last step is using the program slicing. Select: Operations, Image processing, slicing. Select raster map: **Weight**. Select output raster map: hazard. Select domain: **hazard**. Press show and OK.
- Evaluate the output map with **Pixel information**. If necessary adjust the boundary values of the domain hazard and run slicing again, until you are satisfied with the result

- It is also important to include the areas occupied by old landslides in the hazard map. We can do this with the formula:

Final:=iff(isundef(slides),hazard,iff(active=1,"high hazard",iff((slides="bre")or(slides="sre"), "high hazard", "Moderate hazard"))))

9.7 Additional remarks



- You can automate the calculation procedure by using a script, which contains the formulas for the ILWIS operations. Parameters can be used in the form of %1 - %9. You can make a script by copying the statement which is shown on the command line when executing an operation, and pasting it into a script file. Table calculation formulas need the word TABCALC in front. For more information on scripts, consult the ILWIS Help, or the ILWIS User's Guide.
- The method was only done using two parameter maps, just to show the procedure. In reality many more parameter are used. The method is also used to differentiate the parameters according to their importance.
- The analysis should actually be done for different landslide types separately, as they will all have different combinations of causal factors.
- It is very important in real application to validate the output map, This can be done using the success rate method developed by Chung and Fabbri. It should be done using two sets of landslides: one for making the model, and one for checking the result. The best is to use two landslides sets that have been originated in two different periods.
- The Hazard index method is a useful, but simple method. Many more methods exist for landslide hazard assessment, which might be more appropriate, given the objectives of the study, the size of the area, and the available input data.

```
del active.* -force
del active%1.* -force
del %1w.* -force
```

```
active:=iff(isundef(slides),0,iff((slides="br")or(slides="sr"),1,0))
```

```
Active%1.tbt = TableCross(%1,active,IgnoreUndefs)
Tabcalc Active%1 AAct:=iff(active=1,Area,0)
Tabcalc Active%1 AreaAct:=iff(AAct=0,1,AAct)
```

```
crtb1 %1w %1
Tabcalc %1w Areaclassact:= ColumnJoinSum(Active%1.tbt,AreaAct,%1,1)
Tabcalc %1w Areaclassatot:= ColumnJoinSum(Active%1.tbt,Area,%1,1)
Tabcalc %1w densclass:=areaclassact/areaclassatot
Tabcalc %1w weight:=ln(densclass/0.0161)
active%1 = MapAttribute(%1,%1w.tbt.weight)
```

10. Landslide loss estimation.

Once we have generated a landslide susceptibility map we can now proceed with the loss calculation. This will be done only on a qualitative basis as we do not have information on the landslide probability. We will use the landslide hazard map, in which the actual landslides have been included as high hazard if they are active or as moderate hazard if they are old landslides. We will calculate the number of building located in high moderate and low hazard zones. The landslide susceptibility map is called **HazFinal**.



- Rasterize the map **mapping_units** using the georeference **Somewhere..**
- Select *Operations / Raster Operations / Cross* . Cross the raster map **Mapping_units** with the raster map **HazFinal**. Create a cross table **Mapping_units_LSH**.
- In the cross table **Mapping_units_LSH**, first calculate the total area of each mapping unit. Select *Columns / Aggregate*. Select the column **Area**, Function: *Sum*, group by **Mapping_units**, output column: **area_unit**
- We now calculate the fraction of the mapping units that is in high hazard. This can be done through the following formula:

$$\text{LSH_high} = \text{iff}(\text{HazFinal} = \text{"high hazard"}, \text{area}/\text{area_units}, 0)$$
 Use a precision of 0.01
- Now calculate the fraction of the mapping units that is in moderate hazard. Make the formula yourself.
- Close the cross table **Mapping_units_LSH**.

The results can now be joined into the table **mapping_units**.



- Open the table **mapping_units**.
- Join with the table **Mapping_units_LSH** and read in the column **LSH_high** using the aggregation function Maximum.
- Do the same for the column **LSH_moderate**.
- Then you can calculate the number of buildings in each mapping unit which is in high hazard:

$$\text{LS_Risk_high} = \text{LSH_high} * \text{nr_buildings}$$
- Find out the total number of houses in the high landslide hazard class
- Display the results as attribute of the map **Mapping_units**.

The results can be a bit misleading because the losses are shown per mapping unit, especially if the mapping unit is large and located in both steep and flat terrain. Another way is to cross the hazard map **HazFinal** with the map **Floor_nr**.



- Select *Operations / Raster Operations / Cross* . Cross the raster map **Floor_nr** with the raster map **HazFinal**. Create a cross table **Floor_nr_LSH**. Select output map **Floor_nr_LSH**.
- In the cross table **Floor_nr_LSH** indicate the combination of buildings with high hazard. This can be done through the following formula:

LR_high:=iff((hazfinal="high hazard")and(floor_nr>0),1,0)

- Display the result as attribute of the map Floor_nr_LSH (don't forget to link the table to the map in the properties form.
- Compare this result with the previous one. What can you conclude?