Exercise 4. Deterministic landslide hazard assessment

Expected time: 3 hours
Data: data from subdirectory: exercise04
Objectives: This exercise shows you how to carry out a basic slope stability analysis using the infinite slope model. This will calculate the stability of each pixel for different scenarios of the relation groundwater depth / failure surface depth.

Some background information:
The final aim of large scale landslide hazard analysis (scales larger than 1:10,000) is to create quantitative hazard maps. The hazard degree can be expressed by the Safety Factor, which is the ratio between the forces that make the slope fail and those that prevent the slope from failing. F-values larger than 1 indicate stable conditions, and F-values smaller than 1 unstable. At F=1 the slope is at the point of failure.

The infinite slope model can be used on profiles as well as on pixels. The entire analysis requires first the preparation of the data base. The parts on groundwater modelling and the modelling of seismic acceleration are not shown here. For more information see Van Westen (1993). In this exercise only the calculation of average safety factors will be done for different scenarios. These average safety factor maps could be used in the creation of failure probability maps.

Visualization of the input data
In this exercise the slope stability analysis is made by using only two parameter maps: Soildepth (thickness of soil) and Slope_map (slope angles in degrees).

- Open the maps Soildepth and Slope_map and check the values in the maps. Click OK in the Display Options dialog box. The map is displayed.
We assume that:

- The depth of the possible failure lane is taken at the contact of the soil and the underlying weathered rock material.
- All soils have the same values of Cohesion, friction angle and unit weight.

\[ M = \frac{Z_w}{Z} = \frac{\text{Depth to groundwater}}{\text{Depth to failure surface}} \]

In the first part of the exercise we will calculate the stability of the soil cover using only one single value of cohesion, friction angle and bulk density. The consequence of this is that safety factors will not be calculated for the entire area, but only for the areas where there is soil overlying the bedrock.

Besides soil depth which is assumed to be the same as the depth to the failure surface, and the slope of the terrain, we also need to know the other parameters of the infinite slope formula. From laboratory analysis the following average values are known:

\[ c' = \text{effective cohesion (Pa}= N/m^2) = 11000 \text{ Pa} \]
\[ \gamma_w = \text{unit weight of water (N/m}^3\text{)} = 10000 \text{ N/m}^3 \]
\[ z = \text{depth of failure surface below the surface (m)} = \text{map} \]
\[ \beta = \text{slope surface inclination (°)} = \text{map} \]
\[ \phi' = \text{effective angle of shearing resistance (°)} = 32° \]
\[ \tan(\phi') = \text{tangent of the effective angle of shearing resistance} = 0.625 \]

The only unknown parameter yet is the depth of the water table. In the formula this is expressed as the value \( m \), which is the relation between the depth of the water table and the depth of the failure surface.

**Preparation of the data**

Before you can start with the analysis, you need to reorganize the map `Slope_map`. In the calculation we need three parameters that are derived from the slope:

\[ \sin(\text{slope}) = \text{the sine of the slope} \]
\[ \cos(\text{slope}) = \text{the cosine of the slope} \]
\[ \cos^2(\text{slope}) = \cos(\text{slope}) \times \cos(\text{slope}) \]

The ILWIS functions for sine and cosine only work with input values in radians, while our map `Slope_map` is in degrees. Therefore we need to convert to slope map from degrees to radians first.

\[ \text{Slrad} := \text{degrad}(\text{Slope_map}) \]

Now you have the slope in radians, and you can calculate the sine and cosine. You will calculate individual maps for these so that the Safety factor formula (formula 6.1) can be calculated easier.

- Type the following formula on the command line:
  \[ \text{Slrad} := \text{degrad}(\text{Slope_map}) \]
  Accept the default minimum, maximum and precision.

- Open the result map and compare the values of the map `Slrad` with those of the map `Slope_map`. Calculate it with the ILWIS pocket line calculator or the Windows calculator for some pixels, using the formula given above.

- Type the following formula on the command line:
  \[ \text{Si} := \sin(\text{Slrad}) \]
  (with this formula you calculate the sine of the slope).
  Accept the default minimum (-1), maximum (+1) and give a precision of 0.001.

- Open the result map and compare the values of the map `Si` with those of the map `Slrad`. Calculate it with the pocket line calculator or the Windows calculator for some pixels, using the formula given above.

- Type the following formula on the command line:
  \[ \text{Co} := \cos(\text{Slrad}) \]
  (with this formula you calculate the cosine of the slope).
  Accept the default minimum (-1), maximum (+1) and give a precision of 0.001.

- Open the result map and compare the values of the map `Co` with those of the map `Slrad`. Check it for some pixels, using the formula given above.

- Type the following formula on the command line:
  \[ \text{Co} := \cos(\text{Slrad}) \]
  (with this formula you calculate the square of the cosine, using the ILWIS function `seq`).
  Accept the default minimum, maximum and precision.

- Check your results again.
Now all necessary parameters for the formula are known, except for the parameter $m$ related to the groundwater depth.

Creating a function for the infinite slope formula

In the following sections you will use the infinite slope formula extensively for different scenarios, and different input data. To avoid that you have to retype the formula each time, it is better to create a user-defined function for it.

In this dialog box you can edit the expression of the function. Now the expression is:

Function $fs$ (Value Cohesion, Value Gamma, Value M, Value Gammaw, Value Z, Value Co2, Value Tanphi, Value Si, Value Co) : Value

Begin
Return ($Cohesion + (Gamma - M*Gammaw)*Z*Co2*Tanphi) / (Gamma*Z*Si*Co)$
End;

As you can see there are only two variables: Value Gamma and Value M.

Calculating Safety Factors for groundwater scenarios

Now that the function is created, you can start to calculate safety factor maps for different scenarios. In the first part you will calculate the safety factors for different scenarios where only rainfall is the triggering factor. You will not yet look at the influence of an earthquake.

In this dialog box you can edit the expression of the function. Now the expression is:

Function $fs$ (Value Gamma, Value M) : Value

Begin
Return ($10000 + ((Gamma - M*10000)*Soildepth*Co2*0.625) / (Gamma*Soildepth*Si*Co)$
End;

As you can see there are only two variables: Value Gamma and Value M.

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Dry condition

You will first calculate the safety factor for the soils under the assumption that the soil is completely dry. In that case the parameter m is equal to zero.

\[ c' = \text{Effective cohesion (Pa=N/m}^2\) = 11000 \text{ Pa} \]
\[ \gamma = \text{Unit weight of soil (N/m}^3\) = 11000 N/m^3 \]
\[ \gamma_w = \text{Unit weight of water (N/m}^3\) = 10000 N/m^3 \]
\[ z = \text{Depth of failure surface below the surface (m)} = \text{map \textit{Soildepth}} \]
\[ m = \text{Relation z/w (dimensionless)} = 0 \]
\[ \beta = \text{Slope surface inclination (°)} = \text{map \textit{Slope_map}} \]
\[ \phi = \text{Effective angle of shearing resistance (°)} = 32° \]
\[ \tan(\phi) = \text{Tangent of the effective angle of shearing resistance} = 0.625 \]
\[ \sin(\phi) = \text{Sine of slope angle} = \text{map \textit{Slopecos}} \]
\[ \cos(\phi) = \text{Cosine of slope angle} = \text{map \textit{Slopecos}} \]
\[ \cos^2(\beta) = \text{Square of the cosine of slope angle} = \text{map \textit{Slope_cos}} \]

Now you can start with the actual calculation of the average safety factor map representing the situation under dry conditions. The two variables for the function \( f_s \) are 11000 (Value Gamma) and 0 (Value M).

\[ F_{dry} := f_s(11000,0) \]

Use a minimum of 0, a maximum of 100, and a precision of 0.1.

Open the result map and compare the values of the map \( F_{dry} \) with those of the input maps. Calculate the safety factor manually for some pixels with the Pocket line calculator or the Windows calculator, using the infinite slope formula

\[ F_{dry} := \frac{c' \cos(\beta)}{\gamma - \gamma_w} \]

The resultant map \( F_{dry} \) will have some pixels with missing values indicated by a question mark (?). You can investigate these pixels and see that the values of the pixels cannot be calculated either because they lack soil or because they are flat areas. Both conditions indicate stability and thus can be safely grouped as stable.

As you can imagine a situation with a completely dry situation does not occur in a tropical region such as RiskCity, which receives quite a lot of rainfall each year. In any case the map \( F_{dry} \) gives the most stable situation. Let us see how much percent of the area is unstable under these conditions. In order to know that we will first classify the map \( F_{dry} \) into three classes:

- Unstable = safety factor lower than 1
- Critical = safety factor between 1 and 1.5
- Stable = safety factor above 1.5

Create a new domain \( \text{Stabil} \) (type class, group) with the following three classes:

<table>
<thead>
<tr>
<th>Boundary</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unstable</td>
</tr>
<tr>
<td>1.5</td>
<td>Critical</td>
</tr>
<tr>
<td>100</td>
<td>Stable</td>
</tr>
</tbody>
</table>

Now that we have calculated all scenarios, we can compare them. This can be done in a table.
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**Partially saturated condition**

- Create a table from the domain Stabil. In the catalog right click on the domain Stabil and select create a table. Call the new table Stabil.
- Go to Columns, Join and select in the field Table, the histogram of Fdryc; use the column Npixpct. Give the name Dry to the output column. Accept the default values and click Ok.
- Also join the histogram file of the map Fsatc. Give the name Sat.
- Click the button Graph in the main menu of the table Stabil. Remove the tick mark in the X axis, Select Dry as Y axis and click OK. You will see a histogram of the percentage area under different stability classes in dry condition.
- In the Graph window itself, go to Edit menu, Add Graph and select from columns. Select Y axis Sat. Now you will see the histograms of the percentage area under different stability classes in dry and saturated conditions side by side.
- Draw conclusions on the effect of the groundwater on the stability of the soils in the area.

For experienced ILWIS users:

**Using different values for cohesion and friction angle**
- It is also important to include different values for cohesion, friction angle and unit weight of soils for different soil or lithological types. You can do that by adding columns Cohesion, FrictionAngle and Gamma to the table Lithology.

**Using different failure depths**
- In the exercise we only used one failure depth, taken as the soil depth. This is not very realistic. Calculate the stability for different failure depths: 2, 3, 5, and 10 meters.

**Finding out the critical m values**
- Design a method to find out the critical m values that will make the slope at equilibrium (F=1) for different soil depth and slope combinations.

**Ye assume that:**
- The soil change with the same boundary of the lithological map. Also we will use for the soil the maximum value of the cohesion.

- Open the lithology table. Create a new column Cohesion. Select the range between 0 and 9999999.9.

- For experienced ILWIS users:
  - Using different values for cohesion and friction angle
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Input data

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope_cl</td>
<td>Raster</td>
<td>Slope class map</td>
</tr>
<tr>
<td>Aspect_cl</td>
<td>Raster</td>
<td>Slope direction map (with classes)</td>
</tr>
<tr>
<td>Lithology</td>
<td>Raster</td>
<td>Lithological map</td>
</tr>
<tr>
<td>Solid depth</td>
<td>Raster</td>
<td>Solid depth map</td>
</tr>
<tr>
<td>Landuse</td>
<td>Raster</td>
<td>Landuse map</td>
</tr>
<tr>
<td>River_dis</td>
<td>Raster</td>
<td>Distance from rivers</td>
</tr>
<tr>
<td>Road_dis</td>
<td>Raster</td>
<td>Distance from roads</td>
</tr>
<tr>
<td>Landslide data</td>
<td>Raster map</td>
<td>Points each of the interpreted landslides</td>
</tr>
<tr>
<td>Landslide_ID</td>
<td>Table</td>
<td>Attribute table with information on the landslides</td>
</tr>
<tr>
<td>Other data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building_map_segments</td>
<td>Segment map</td>
<td>Boundary lines of the buildings in the area.</td>
</tr>
<tr>
<td>High_res_image</td>
<td>Raster</td>
<td>High resolution image of the study area.</td>
</tr>
</tbody>
</table>

For experienced ILWIS users:

Creating slope and aspect maps:

- Create a DTM by interpolation of the contours (Operations / Interpolation / Contour interpolation).
- To calculate height differences in X-direction: start the Filter operation, select the Digital Elevation Model as the input map and select linear filter dfdx. Call the output map for example DX. Do the same for the y direction, using filter dfdy. Name output: DY.
- Calculate the slope in degrees using the formula in MapCalc:
  \[
  \text{SLOPEDEG} = \text{RADDEG}(\text{ATAN}(\text{HYP}(\text{DX}, \text{DY}) / \text{PIXSIZE}(\text{DEM})))
  \]
- Calculate the aspect in degree using the following formula:
  \[
  \text{ASPECTDEG} = \text{RADDEG}(\text{ATAN2} (\text{DX}, \text{DY}) + \pi)
  \]
- The map Slope still needs to be classified into classes (File/Create/Domain). Make a class (don’t forget to indicate the option group) domain Slopec. and add the slope classes you want to differentiate. E.g. 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 Slopec. Name the output map Slopec. Same procedure for Aspect.
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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.

Conditional statements (IFF): If a is true, then return b, else return c.
IFF returns:
- if a=false, c is returned;
- if a=undefined, undefined is returned.
- The amount of nested IFF statements is unlimited.
When the definition symbol := is used, the dependency link is immediately broken after the output map/column has been calculated.

MapCalc and TabCalc:
The same type of formulas can be used on columns in tables (called Table Calculation or TabCalc) and also on maps in the command line to the main window (called Map Calculation or MapCalc).

Undefined values:
These are indicated by a question mark (?). They either indicate missing values, unknown values, values outside the value range, or the area outside the study area.

Step 1: 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 map Slope_cl is selected as example. First the map crossings between the occurrence map and the two parameter maps have to be carried out.

Map crossing:
The Cross operation performs an overlay of two raster maps. Pixels on the same positions in both maps are compared; the occurring combinations of class names, identifiers or values of pixels in the first input map and those of pixels in the second input map are stored. 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.

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

Step 2: 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 opened.

Step 2.1: In this table create a column in which only the area of active landslide are indicated by typing the following formula on the command line of the table window:

AreaAct:=iff(Active=1,area,0)

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

Step 2.2: 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 Slope_cl. Deselect the box Output Table, and enter the output column Areasloptot. Press OK. Select a precision of 1.0.

Step 2.3: Calculate the area with active landslides in each slope class.

Again select from the table menu: Columns, Aggregation.

Select the column: AreaAct. Select the function Sum. Select group by column Slope_cl. Deselect the box Output Table, and enter the output column Areaslopeact. Press OK. Select a precision of 1.0.

Step 2.4: 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 2.5: 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 Areasmapact. Press OK. Select a precision of 1.0.

Step 2.6: Calculate the landslide density per slope class.

Type:
Densclas:=Areaslopeact/Areasloptot

Select a precision of 0.0001.

Step 2.7: Calculate the landslide density for the entire map.

Type:
Densmap:=Areamaptot/Areamaptot

Select a precision of 0.0001 and decimal: 4.

Hint: If Densclas and Densmap are not in 4 decimals then use property dialog box to change the decimal.

The result will look like below:
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Now you have calculated all the required densities for the map Slope_cl

Step 3: 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 = 213446 / 14000000 = 0.0152

Previously the calculation was done on the cross-table for the maps Slope_cl and Active. As you could see from the table above, 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 below instead, where each slope class occupies only one record. That is why you will work now with the attribute table connected to the map Slope_cl and use table joining combined with aggregation to obtain the data from the cross table.

- Create a table Slope_cl for the domain Slope_cl. (In the main window of ILWIS go to File, create, table. See the image on the left). 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.

  - 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 output column Areaslopact. Press OK. (You can obtain the same results with the aggregation function. If you want to verify it, open the Actslope table, aggregate the column Areaact using the sum function, and storing the result in the table Slope_cl, and call for example the new column Areasloptot_aggregate).

  - Step 3: With both columns, you can calculate the landslide density in each slope class with the formula:

    \[ \text{Densclas} := \frac{\text{Areaslopact}}{\text{Areasloptot}} \]

    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:

  \[ \text{Dclas} := \text{iff}(\text{Densclas}=0, 0.0001, \text{Densclas}) \]

- The final weight can now be calculated with the formula:

  \[ \text{Weight} := \ln\left(\frac{\text{Dclas}}{0.0152}\right) \]

- Check the resulting weights in the table. Which slope classes have the most important relation with landslides?

- Close the table.

Step 4: 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 Slope_cl, table Slope_cl. Select attribute Weight. Select output raster map Wslope_cl. Press OK. (See image left)

- Display the resulting map Wslope_cl. Stretch between -2.5 and +2.5

- Use the same procedure the other parameter map Lithology. Name table as Lithology_cl with domain Lithology. The resulting map should be called: WLithology.

- The weights for the two maps can be added with the formula:

  \[ \text{Weight1} = \text{Wslope_cl} + \text{WLithology} \]

- Display the map Weight1 and use the pixel information window in order to read the information from the maps Slope_cl, Wslopecl, Lithology, WLithology and Weight1.

We have evaluated the weight of the slope. Now we need to evaluate the weight of the lithology. The procedure is the same used for the slope.
Now we have to evaluate the weight for each class.

1. **Create a table litho_cl for the domain lithology**. In the main window of ILWIS (in the file create table). See the image on the left.

2. **Select Columns, Join**. Select table Actlithology, select column: Area, select function: Sum, select group by column: lithology. Select output column: Arealithtot. Press OK. Select a precision of 1.0.

3. **Again select from the main ILWIS menu: Operations, Raster operations, Attribute map**. Select raster map lithology, table litho_cl. Select attribute: Weight. Select output raster map: Weight_lithology. Press OK. See the image on the left.

4. **The weights for the two maps can be added with the formula**.

\[
\text{Weight1} = \text{Wslope_cl} + \text{Weight_lithology}
\]

5. Display the map Weight1 and use the pixel information window in order to read the information from the maps Slope_cl, Wslopecl, Lithology, WLithology and Weight1. (See below).

### Step 2: Calculate the area with active landslides in each slope class.


2. **Step 3: With both columns, you can calculate the landslide density in each class with the formula**.

\[
\text{Densclas} = \frac{\text{Arealithoact}}{\text{Arealithtot}}
\]

3. Select a precision of 0.0001.

4. There are some classes with a density of 0. To adjust type the following formula:

\[
\text{Dclas} = \text{iff}(\text{Densclas} = 0, 0.0001, \text{Densclas})
\]

5. The final weight can now be calculated with the formula:

\[
\text{Weight} = \ln(\frac{\text{Dclas}}{0.0152})
\]

6. Check the resulting weights in the table. Which lithology classes have the most important relation with landslides?
Step 5: Use of scripts (to calculate for all factor maps)

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.

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**Script:**

A script is a sequenced list of ILWIS commands and expressions. By creating a script, you can build a complete GIS or Remote Sensing analysis for your own research discipline. Each line in a script is a statement that is executed via the ILWIS command line of the Main window. Via a script, you can for instance handle some necessary object management (e.g. copy or delete), display of objects (open or show), and the creation and calculation of data objects. All map and table calculations, and all ILWIS expressions to perform operations may be used. Furthermore, you can call other scripts and start other Windows applications from within a script.

- The script that is given on the next page can be used to automate the analysis. Select File/Create/Script, and copy the text in the script window. Save the script as `Weights`.
- Then close the script and run the script on the command line: `Run weights Slope_cl`
- Similarly you can also run the script for other parameter maps that you consider important for landslide occurrence. Such as Lithology, or landuse or distance from the river etc.

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**Parameters in scripts:**

A script can use parameters. Parameters in a script replace (parts of) object names, operations, etc. Parameters in scripts work as DOS replaceable parameters in DOS batch files, and must be written on the Script Tab in the script editor as `%1, %2, %3, up to %9`.

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After running the script you can check the weights in the attribute table to evaluate whether the parameter map is a useful tool for landslide prediction. You might also have to combine different parameters, into new more meaningful ones. This is an iterative process.
Step 6: Combining the weights in a final susceptibility map

After running the script for all the factor maps, and after selecting which maps you want to use in the creation of the final map, you can add up the weights into a final weight map.

- In the command line calculate the following equation to add up the weight maps:
  \[
  \text{Weight} := \text{activeaspect_cl} + \text{activeslope_cl} + \text{activelihtology} + \text{activelanduse} + \text{activeriver_dis}
  \]

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.

1. Calculate the histogram of the map Weight and select the boundary values for three classes: Low hazard, Moderate hazard, and High hazard.
2. Create a new domain: Susceptibility. 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.
3. The last step is using the program slicing. Select: Operations, Image processing, slicing. Select raster map: Weight. Select output raster map: hazard. Select domain: Susceptibility. Press show and OK.
4. 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.

For experienced ILWIS users:

- It is also important to include the areas occupied by old landslides in the hazard map. You can do this with a map calculation formula. Design the procedure and formula's yourself. Give it the name Final

We are going to assume that for the areas classified as "low_hazard", but affected by landslides in the past, the hazard could be moderate.
Step 7: Calculating success rate.

The "predictive power" of the resulting weight maps can be tested by analysing 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.

- Create a script for the calculation of the success rate, using the example script below. Call it: success
- Run the success rate script as follows:
  - Run success weight
- After running the script, open the table Activeweight. Open the Display in a graph the column percentmap on the X-axis and the column percentlandslide on the Y-axis. Evaluate the results 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.

```plaintext
//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 := Cumulative(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 as y-axis and Percentmap as x-axis
```

Some final remarks:
- The method was only done using a limited number of 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.
- 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.

For experienced ILWIS users:
- There is also another script in the directory which can be used for calculating a more complicated method: Weights of Evidence. You can try that as well if you like.
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 Npx and group them by %1 //nCLASS = number of pixels with landslides in the class. We sum the values from columns Npxact and group them by %1 //nMAP = number of pixels with landslides in the map. We sum the values from columns Npx and don't group them //nSIDE = number of pixels with landslide in the map. We sum the values from columns Npxact 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.nclass = ColumnJoinSum(s%1.tbt,Npixact,%1,1)
Tabcalc s%1 %1.nmap = ColumnJoinSum(s%1.tbt,Npix,%1,1) Tabcalc s%1 %1.nside = ColumnJoinSum(s%1.tbt,Npixact,%1,1)

//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 s%1 npix1 =Iff((nclass>0),nclass,1) Tabcalc s%1 npix2 = Iff((inside-nclass)=0,1,inside-nclass) Tabcalc s%1 npix3 = Iff((nmap-nclass)=0,1,nclass-nclass) Tabcalc s%1 npix4 = nmap-inside-nclass

//NOW WE CALCULATE THE WEIGHTS IN THE ATTRIBUTE TABLE Tabcalc s%1 wplus (dom=value.dom; vr=-10:10:0.00001) = LN((npix1/(npix1+npix2))/(npix3/(npix3+npix4))) Tabcalc s%1 wminus (dom=value.dom; vr=-10:10:0.00001)  = LN((npix2/(npix1+npix2))/(npix4/(npix3+npix4)))

//NOW WE CALCULATE THE CONTRAST FACTOR Tabcalc s%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 s%1 WminSum=aggsum(wminus) Tabcalc s%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