GIS CASE STUDY

Application of GIS for hazard and risk assessment: Tegucigalpa, Honduras

Part 4: Landslide hazard mapping

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This exercise deals with the evaluation of landslide distribution and landslide hazard for a part of Tegucigalpa. It consists of two parts:

- In the first part of the exercise you will interpret landslides using a digitial stereo image, and on-screen digitizing. You can either use an analgyph image or a screen-stereoscope for the interpretation. You will concentrate on the interpretation of large fossil landslides in the area
- The second part deals with the generation of the simple landslide hazard map using statistical analysis, with only two input parameters: slope and lithology.

Disclaimer

The material in this exercise is for training purposes only. The results should not be used in actual planning of the city of Tegucigalpa as ITC does not guarantee the accuracy and precision of the input data.

The GIS software that will be used in this exercise is the Integrated Land and Water Information System (ILWIS), version 3.11, developed by the International Institute for Geo-Information Science and Earth Observation (ITC). Information: www.itc.nl

Acknowledgements

We would like to thank Gonzalo Ernesto Funes Siercke from COPECO for providing us the data.

4.1 On-screen digitizing of landslides on a Stereo image

Time requirement: 2 hours

Objectives:

- On-screen digitize the landslides that can be identified on the orthoimage image.
- Generate a segment map and a point map, which will be combined into a polygon map.
- Discuss about the causal factors for landslides in the area

Data needed:

- Ortho image: **Ortho_tegu** (year 200?), (raster image)
- Stereo image in colour, for use with screenscope: **Ortho_stereo**
- Stereo image in black and white, to be used as anaglyph: **Ortho_stereo_bw**
- Map of the landslides: **Landslide_map**(segement map). This map is made by combining several landslide inventory maps.

For the city of Tegucigalpa several landslide inventory maps are available in digital format. However, they do not contain the same landslides, and some of the mapped landslides are quite questionable, whereas other landslides have not been mapped. We will therefore check the landslide ourselves using the anaglyph image.

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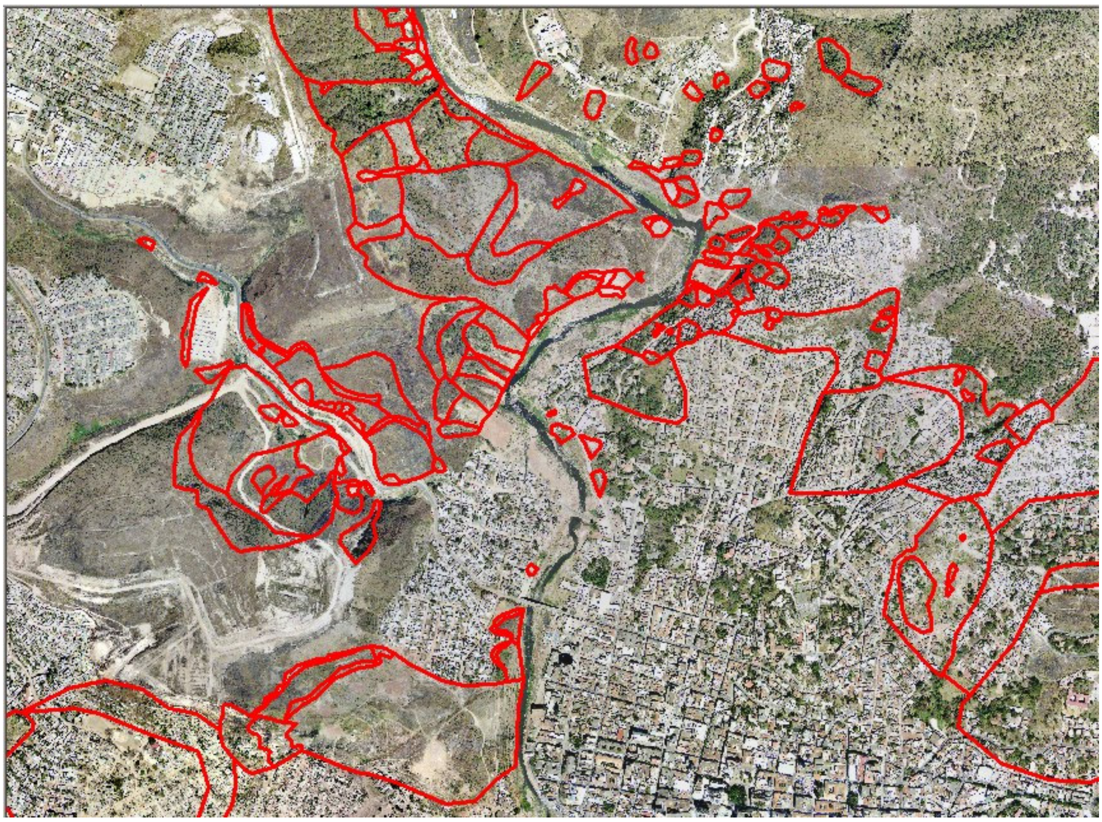
- Open the map **Ortho_tegu_bw** as anaglyph map. Add the segement map **Landslide_map** to it. Zoom in on some of the landslide areas.. Use anaglyph glasses to get stereo.
- As you can see the landslide have not been mapped very accurately. Quite some editing would have to be made, and new landslides added.
- In the map window of **Ortho_tegu** select *Edit / Edit layer* and select the segment map **Landslide_map**
- Next you must on-screen-digitize the boundary of the landslides that you can recognize. Given the resolution of the imagery available, one can distinguish quite well the various landslides using the anaglyph images or using a screen stereoscope. Use the pen in the editor menu to digitize new ones, the small hand to delete segments that are not correct. Compare with the three dimensional image in the anaglyph.

- Make sure to connect all lines together.
- When you finish digitizing one segment, select the segment with the *Select Mode* icon (the hand) and choose the correct class (**Landslides**). Next select the *Insert Mode* icon (the pencil) and digitize the following segment.
- When you agree with digitized lines that are already in the file, you have to give them a different name (**Landslides**). Click on the segment with the hand, right click and select Edit. Then select the name **Landslide** from the list.

An example of a landslide interpretation is shown below.



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- When you are finished with landslide interpretation, you will have to generate a new segment map, containing only those segments that you added. Close the editor. Select from the menu: *Operations / Vector Operations / Segments / Mask Segments*. Select the segment file **Landslide_map**, the mask **Landslides**, and the output segment map **Landslides**. Only those segments with the code Landslides will be copied to new file.
- Before you can edit the new file **Landslides**, first break the dependency (in the properties form).
- Before you can polygonize you need to check the segments. Open the map **Landslides**. Go to the *File* menu and select *Check Segments*. Select *Self Overlap*. Repair all the mistakes. Ask a teacher to assist you the first time.
- Then check segments using *Dead Ends*, and *Intersections*. Repair all mistakes.
- When you finish digitizing one segment, select the segment with the *Select Mode* icon (the hand) and choose the correct class (new landslides). Next select the *Insert Mode* icon (the pencil) and digitize the following segment.
- When you are finished with the digitizing procedure, you need to check the segments. Go to the *File* menu and select *Check Segments*. Select *Self Overlap*. Repair all the mistakes. Ask a teacher to assist you the first time.
- Then check segments using *Dead Ends*, and *Intersections*. Repair all mistakes. When you are finished, close the editor.

- The next step is to create label-points for the polygons you are going to make. Open the map **Ortho_tegu**, and add the segment map **Landslides** to it. The go to *File / Create Point Map*. Name the new point map **Landslides**, and make a class domain **Landslides**, containing the name shown below in the table.

Code	**Name**
Bf	Body of fossil landslide
Bre	Body of reactivated landslide
Br	Body of recent landslide
PL	Possible landslide
PLA	Potential landslide area
Sf	Scarp of fossil landslide
Sre	Scarp of reactivated landslide
Sr	Scarp of recent landslide

Table 4.1: Landslide classes

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- Digitize a label point inside of each polygon, and give it the name of one of the classes from the above table. Do this for all the polygons that you indentified. Make sure you don't forget to label polygons. When you are finished, close the editor.
- Next you will attempt to polygonize it. In the main window go to *Operations / Vectorize / Segments to Polygons* . Select segment map **Landslides**, label point file: **Landslides**, and output map **Landslides** (it is a polygon mpa, so you can use the same names as the segement and point maps).
- Check the result. If there are still mistakes, you have to either edit the segment map or the point map, and then make the polygon map up to date. When you finish, go to the File Menu and select Exit Editor

After having made the interpretations, which conclusions can you make regarding the most important causal factors for landslides in the study area?

4.2 Statistical landslide hazard assessment

This method is based upon the following formula:

$$\ln W_i = \ln\left(\frac{\text{Densclas}}{\text{Densmap}}\right) = \ln\left(\frac{\frac{\text{Area(Si)}}{\text{Area(Ni)}}}{\frac{\sum \text{Area(Si)}}{\sum \text{Area(Ni)}}}\right) \qquad [4.1]$$

where,

Wi =	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 figure 5.1.

Time required: 2.5 hours

Data needed:

- A landslide map made in a similar way as you did in the previous exercise. You may use your own map, or copy the map **Slides** from the directory /results into your work directory.
- 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).

4.2.1 Visualization of the input data

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

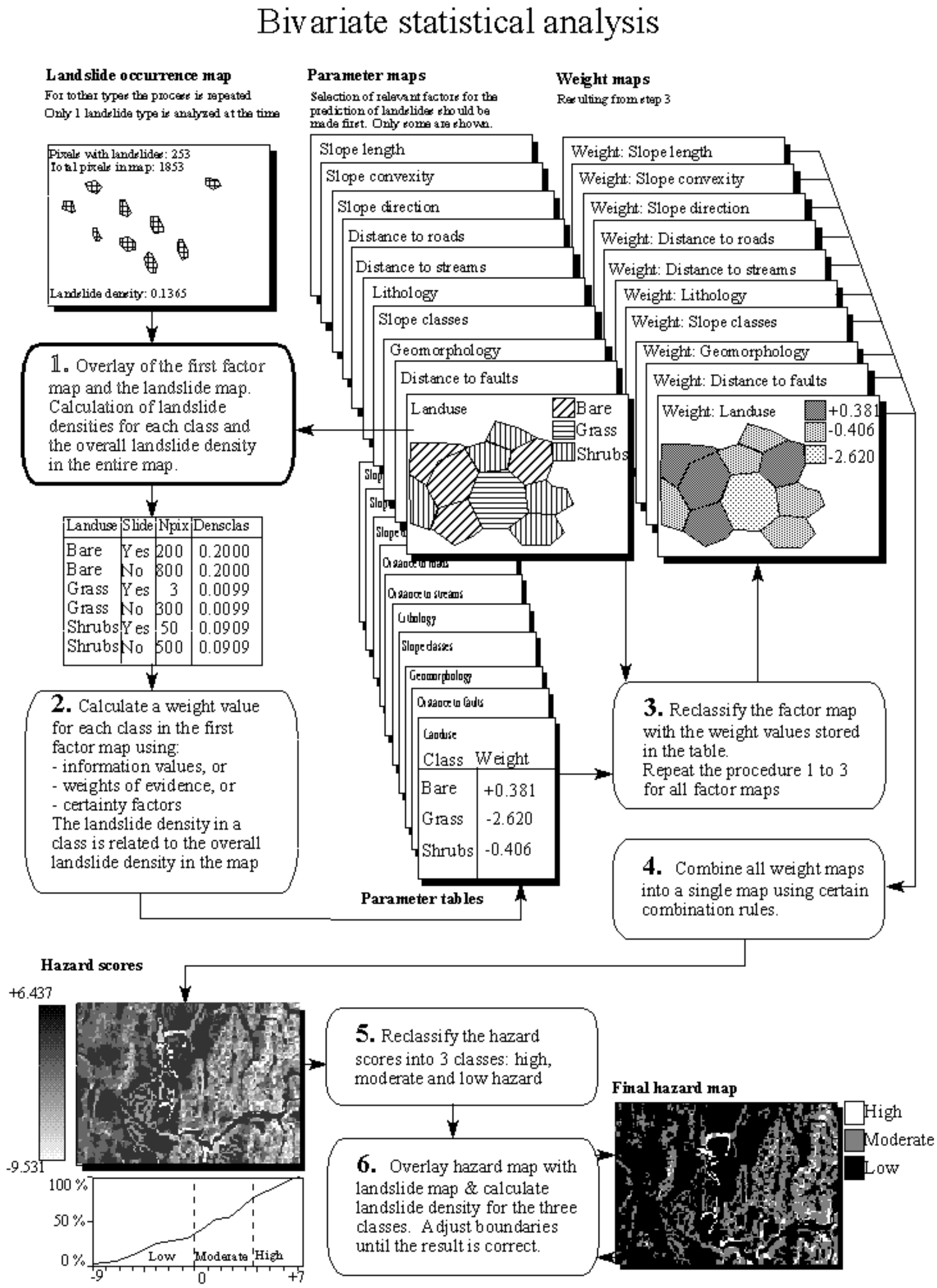

Figure 1: Simplified flowchart for bivariate statistical analysis. In this exercise only 2 input maps are used

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- Open the map **Otho_tegu** 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).

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- 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 **Tegucigalpa** 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.

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- We are going to use only the classes Br (body of recent landslides) and Sr (scarp of recent landslides). See table 4.1.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.

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- **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:

  SLOPEPCT = 100 * HYP(DFDX,DFDY) and

  SLOPE = RADDEG(ATAN(SLOPEPCT/100))
- Also make a slope map of the Lidar_dem. Check the differences.

4.3 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.

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- 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`**. 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.

4.4 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.

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- 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:

`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:** 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 Areas`loptot`. 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: Areas`lopeact`. 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: Area`maptot`. 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: AreaA`ct`. Select the function Sum. Deselect the box group by. Deselect the box Output Table, and enter the output column: Area`mapact`. Press OK. Select a step size of `1.0`.
- **Step 6:** Calculate the landslide density per slope class
  Type:

  `Densclas=Areaslopeact/Areasloptot↵`

  Select a precision of `0.0001`.
- **Step 7:** Calculate the landslide density for the entire map.
  Type:

  `Densmap=Areamapact/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 degree	0	3673980	3673980	0	3703788	29808	14000000	225189	0.0080	0.0161
10-20 degree	1	29808	29808	29808	3703788	29808	14000000	225189	0.0080	0.0161
20-30 degree	0	1851024	1851024	0	1899509	48485	14000000	225189	0.0255	0.0161
20-30 degree	1	48485	48485	48485	1899509	48485	14000000	225189	0.0255	0.0161
30-40 degree	0	1038726	1038726	0	1100738	62012	14000000	225189	0.0563	0.0161
30-40 degree	1	62012	62012	62012	1100738	62012	14000000	225189	0.0563	0.0161
40-50 degree	0	355591	355591	0	399912	44321	14000000	225189	0.1108	0.0161
40-50 degree	1	44321	44321	44321	399912	44321	14000000	225189	0.1108	0.0161
50-90 degree	0	132721	132721	0	158144	25423	14000000	225189	0.1608	0.0161
50-90 degree	1	25423	25423	25423	158144	25423	14000000	225189	0.1608	0.0161

Table 4.2: Cross table and calculated columns

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

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- 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.

4.5 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 Slopecl and Active. As you could see from the table 4.2, 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 5.3 instead, where each slope class occupies only one record. That is why you will work now with the attribute table connected to the map Slopecl 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.

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- Create a table for the domain Slopecl. This table contains no additional columns, except the column with the domain. Repeat the procedure from above, but now with table joining.
- **Step 2:** Calculate the total area in each slope class.
  Select Columns, Join. Select table Actslope. Select column: Area. Select function Sum. Select group by column Slopecl. Select output column Areasloptot. Press OK.
- **Step 3:** 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 Slopecl. Select output column Areaslopact. Press OK.
- **Step 6:** With both columns, you can calculate the landslide density in each slope class with the formula:

  `Densclas:=Areaslopact/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:

  `Dclas:=iff(Densclas=0,0.0001,Densclas)↵`
- The final weight can now be calculated with the formula:

  `Weight:=ln(Dclas/0.0161)↵`
- Close the table.

Now you have calculated the weights for the map Slopecl.

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

4.6 Creating the weight maps

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

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- Select from the main ILWIS menu: Operations, Raster operations, Attribute map. Select raster map Slopecl. Select attribute Weight. Select output raster map Wslopecl. Press OK.
- Display the resulting map Wslopecl. 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:

  Weight=Wslopecl+WLithology↵
- Display the map Weight and use the pixel information window in order to read the information from the maps Slopecl, Wslopecl, Lithology, WLithology and Weight.

4.7 Classifying the Weight map into the final hazard map

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

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- 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")))

4.8 Additional exercise

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- Create a script for the calculation of weight values (see ILWIS User's Guide for more information on scripts).

References

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