

## CHAPTER 1

# Hazard, vulnerability and risk analysis

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### Summary

This case study is intended to illustrate the meaning of hazard, vulnerability and risk, using a very simple data set on the national-scale of Colombia (South America). The occurrence of a disaster depends on two factors:

- *hazard*: the probability of occurrence of a potentially damaging phenomenon,
- *vulnerability*: the degree of loss resulting from the occurrence of the phenomenon.

You will first generate a qualitative hazard map by combining several factor maps. Then a vulnerability map is made. The hazard and the vulnerability map are combined into a risk map.

### Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap01. If you have already installed the data on your hard-disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, c:\ilwis21\data\appguide\chap01. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).



- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\appguide\chap01.

## 1.1 Visualization of the data

Before you can start with the actual analysis, it is important to have an idea of the input data. The following raster maps are available:

Colombia	The departments of Colombia.
Landslid	Regions with severe landslide problems.
Volcanic	Regions with volcanic hazards.
Seismic	Regions with seismic hazard.
Tsunami	Regions with tsunami hazard (seismically induced waves).
Inundat	Regions with flood hazards.
Rivers	Regions with torrential river activity.
Beach	Regions with beach erosion and/or accumulation.
Industry	Main industrial regions.
Infraseg	Main infrastructure.
Concentr	Concentration of economic activities.
Topograp	Topographic region of Colombia..

There is only one polygon map present:

Colombia	The departmental boundaries of Colombia.
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### Colombia

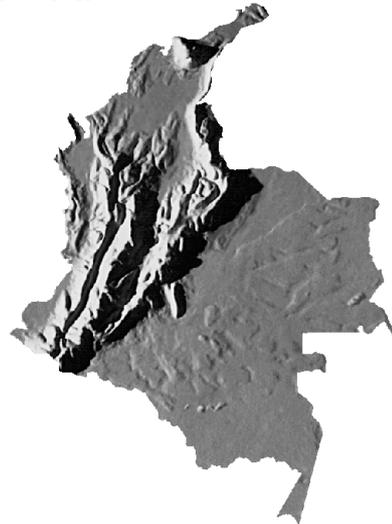


Figure 1.1: Hillshading map of Colombia

You will first have a look at the maps before you start the analysis.



- Double-click the polygon map `Colombia`. Now a `Display Options` dialog box is shown in which you can modify how the map will be shown.
- Select the check box `Boundaries Only`. Accept all default settings and press `OK`. The map is shown in a map window.
- Drag the map window to the side of the screen.
- Drag-and-drop the raster map `Colombia` into the map window. The `Display Options` dialog box is opened. Click `OK`. The raster map `Colombia` is now displayed, together with the boundaries of the polygon map.
- Click on several units in the map to find out their meaning.

Now you will look at the maps that contain information on the different types of hazard in Colombia.



- Drag-and-drop the map `Seismic` into the map window. Accept the defaults in the `Display Options` dialog box and click `OK`. The raster map `Colombia` is now replaced by the raster map `Seismic`. Check the meaning of the mapping units.
- Evaluate the other maps (`Landslid`, `Volcanic`, `Tsunami`, `Inundat`, `Rivers`, `Beach` and `Topograp`) with the same procedure.
- Open the pixel information and drag-and-drop the maps `Colombia`, `Seismic`, `Landslid`, `Volcanic`, `Tsunami`, `Inundat`, `Rivers`, `Beach` and `Topograp` to it. Check the combined information of the maps while you move the mouse pointer through the map window.

Also have a look at the maps used for the vulnerability analysis.



- Drag-and-drop the map `Seismic` to the map window. Accept the defaults in the `Display Options` dialog box and click `OK`. Raster map `Colombia` is now replaced by the raster map `Seismic`.

- Check the meaning of the mapping units.
- Evaluate the other maps (Industry, Infraseg and Concentr) by dragging and dropping them in the map window. Check their contents.
- Add these maps also to the pixel information window. Check the combined information of the maps while you move the mouse pointer through the map window.
- Close the map window and the pixel information window

When you have a sufficient idea of the input data you can continue with the next topic.

## 1.2 Creating the hazard map

In this exercise you will look at the first aspect: *hazard*. In later exercises you will evaluate the *vulnerability* and finally the *risk*. The degree of hazard of a certain area is determined by a combination of factors. The different factors, which influence the degree of hazard, can be observed separately, although they do influence each other (e.g. in an area with high seismic hazard there will be more landslides). The factors are provided in the form of parameter maps, each of them describing a potentially damaging phenomenon. The following phenomena are taken into account:

- landslides
- seismic hazard
- tsunami hazard: earthquake induced flood waves
- volcanic hazard
- flood hazard
- erosional hazard by torrential rivers
- beach erosion and accretion
- topographic regions

In the previous section you have seen the spatial distribution of the various hazards in Colombia. The next step is to combine this information into one map. You can follow two approaches:

- Simply sum up all the maps, with equal weight, or
- Assign different weights to different hazard types.

Here you will follow the second approach. The impact of the different hazards to human activity is not equal for all types of hazards. Strong earthquakes will have a much more devastating effect on an area than landslides. Therefore you have to

assign weights to each of the classes within the individual hazard maps, taking into account their importance in producing damage.

The amount of weight that will be given to a certain factor and the way this factor will be classified is highly subjective. This method is also referred to in the literature as *blind weighting*, as we do not dispose of quantitative data to decide whether the relation between high seismic hazard and high landslide hazard should be 1 or 10 or 100. The experts opinion is used in defining these weights. This has the consequence that nearly every scientist may assign different values.

Later on the weighting values will be used instead of the map-values. In this way, the separated parameter maps of the factors involved in the hazard-analysis become weighting maps.

This exercise consists of several steps:

- **Step 1: Assigning weight values to the classes of the parameter maps.**  
The weighting values will be assigned in tables connected to the raster maps. You will create a table for each map and then create a column weight, in which you will edit the weight values for the different classes.
- **Step 2: Renumbering the parameter maps to weight maps.**  
The combination of each parameter map with the weight values derived from the table created in the previous step is called *renumbering*. This way you will change the maps with classes into value maps, with weight values.
- **Step 3: Combining the weight maps into one single hazard map.**  
The weight maps will be combined in this exercise by simply summing them up. It is also possible to define weights to the individual maps. For example, the weights for seismic hazard can be two times as important as those for landslide hazard.
- **Step 4: Classifying the combined weight map into a final hazard map.**  
The combined weight map, which has many classes, will be simplified by classifying the values into four classes.

In chapter 17 more detailed examples are given of various GIS techniques for qualitative map combination.

### Step 1: Assigning weight values using attribute tables

The weight values that should be assigned to the individual classes are given in the tables below:

#### Seismic

Legend	Weight
High seismic hazard	10
Moderate seismic hazard	5
Low seismic hazard	0

### Volcanic

Legend	Weight
No Volcanic hazard	0
Volcanic hazard	10

### Landslid

Legend	Weight
Narino	2
Region Huila	2
Valle de Cauca	3
Zona Cafetera	4
Manizales y alrededores	4
Valle de Aburra	4
Cundinamarca	3
Boyaca and Santander	2
Bucaramanga	2
No landslide hazard	0

### Tsunami

Legend	Weight
Tsunami hazard	10
No tsunami hazard	0

### Beach

Legend	Weight
Accumulation	0
Accumulation and Erosion	1
Erosion	2
No accumulation or erosion	0

All classes in the map Inundat will all receive a weight of 5. Class "No inundation hazard" will receive a weight of 0.

All classes in the map River will receive a weight of 4. Class "No river" will receive a weight of 0.

All classes in the map Topograp will receive a weight of 2, and only class "Altitude less than 1000 m" a weight of 0.

Here only the procedure for the first map (Seismic) is explained. The other maps can be treated with the same procedure.



- Select the menu options: File, Create, Create Table.

- Enter the following filename: `seismic`. Select the domain `Seismic` and click on `OK`. A domain in ILWIS determines the content of a map, or a table. If we have classes, the domain is a list of the possible names of the classes. A table which will be linked to a map should therefore have the same domain. The table is now shown. You see the domain items in the gray column on the left hand side.
- Select: `Columns, Add Column`. Enter the column name: `Weight`, and select the domain: `Value`. Enter the values `0` and `10` for the value range, and `1.0` for the precision. Click `OK`.
- Fill in the weights of the three classes, as indicated in the table on the previous page.
- Close the table.

Now you have made a table with weight values for the map `Seismic`.



- Repeat the same procedure for the maps `Landslid`, `Volcanic`, `Tsunami` and `Beach`. Create a table for each map using its own domain.

Before you can go on to the next step you still have to indicate that the tables should be linked to the maps. This is done by changing the *properties* of a map.



- Click with the right mouse button on the map `seismic` and select from the context-sensitive menu the option `Properties`. Now a dialog box appears in which the properties of the map are shown, such as the domain, the number of pixels, etc.
- Click on the option `Attribute Table` and select the table `Seismic`.
- Press `OK`. Now the table `seismic` is linked to the map `seismic`.
- Follow the same procedure for the other maps (`Landslid`, `Volcanic`, `Tsunami` and `Beach`).

The creation of weights for the other three maps (`Inundat`, `River`, and `Topograp`) will be done differently. Since practically all units will receive the same weight it is better to use another method of reclassification: a Map calculation formula.

### Step 2: Renumbering the parameter maps to weight maps

Now that you have made a table with weight values for the parameter maps, we can now renumber the maps to weight maps. For this operation we will use the operation **Attribras**.



- From the menu of the Main window, select the menu items: **Operations, Raster operations, Attribute Map**.  
Select **Seismic** as the raster map; select **Seismic** as the table and **Weight** as the attribute. Type **Wseismic** as output map.
- Type: **Renumbered map Seismic with weights as Description**.
- Click **Show** and **OK**.
- In the **Display Options** dialog box, select the representation **Pseudo**. Click **OK**. The weight map is displayed.
- If you click on a unit in the map, you will no longer see a description, but a number, which is the weight assigned earlier.
- To check this with the original map **Seismic** use the **PixelInfo**. You can do this by selecting **File, Open Pixel Information**. In the pixel information window, select **File, Add Map** and select the map **Seismic**. When you move the mouse over the map, you will see the name of the original unit in map **Seismic** and the weight value.
- Close the map window and the pixel information window.

Now you have renumbered the map **Seismic** into a weight map **Wseismic**.



- Repeat the same procedure for the maps **Landslid, Volcanic, Tsunami** and **Beach**. Creating weight maps called: **Wlandslid, Wvolcani, Wtsunami** and **Wbeach**.

Now another method will be used to reclassify the maps **Inundat, River** and **Topograp**. You will directly create the weight map, using a formula, without first storing the weights in a table.



- Type the following formula on the command line of the main ILWIS window:

```
Winundat=iff(Inundat="No inundation hazard",0,5)↵
```

- In the Raster Map Definition dialog box, select the domain Value with values range between 0 and 5 and a precision of 1.0. Click OK. No calculation takes place yet. Only the definition is stored and a raster map icon for the map Winundat is made. The actual calculation takes place only after opening the map.
- Double-click raster map Winundat. The map is calculated, before the Display Options dialog box is opened. Select the representation Pseudo, and click OK.
- Design the formula for creating the map Wriver yourself. All classes of the input map River will get the value of 4, except for the class "No river" which gets 0.
- Also make the map Wtopogra, in which all classes of the input map Topograp will get the value of 2, except for the class "Altitude less than 1000 m", which gets 0. Make sure not to make a typing mistake in the long name, otherwise the result will be undefined.

Now you have all the weight maps ready.

### Step 3: Combining the weight maps

The next step in the creation of the hazard map is the combination of the individual weight maps.



- Type the following formula on the command line:

```
Hazard=Wseismic+Wlandsli+Wvolcani+Wbeach+Wtsunami+Wriver+Winundat+Wtopogra↵
```

- Click OK in the Raster Map Definition dialog box.
- Display the map Hazard. Use the Pseudo representation.
- Use the pixel information window to read the values of the input maps, together with those of the map Hazard. Check if the computer can add up values correctly.
- Close the map window and the pixel information window.

### Step 4: Classifying the hazard map

The hazard map which was made in the previous section has many different values. The range of values can be evaluated by calculating a histogram.



- In the Main window, select the following menu items: **Operations, Statistics, Histogram**.  
Select the map `Hazard` and click **OK**. The histogram is calculated and the result shown in a table.
- In the table window, select the menu items: **Options, Show Graph**. The Graph dialog box is opened.  
Select `Value` for the X-axis and `Npix` for the Y-axis and click **OK**. The Edit Graph dialog box is opened.  
Select: `line` and click **OK**. The histogram will be shown on the screen. Evaluate the values in the histogram. On the basis of these values we can make a subdivision in hazard classes.
- Close the graph and the histogram table.

From the range of values you can see that the best way to classify the map hazard is to divide it into classes of 5 units.



- In the Main window, select **File, Create, Create Domain**. Create a new domain `Hazclas`. Select the options `Class` and `Group`. Click **OK**. The Domain Editor is opened.  
Select **Edit, Add Item** and fill in the following classes:

Boundary	Class
5	Very low hazard
10	Low hazard
15	Moderately low hazard
20	Moderate hazard
25	High hazard
100	Very high hazard
- Close the Domain Editor.
- In the Main window, select: **Operations, Image Processing, Slicing**. Select the raster map `Hazard` and give `Hazclas` as the output raster map. Use the domain `Hazclas`. Click **OK**.

- Open the representation of `Hazclas`, and edit the colors so that “Very low” is green and “Very high” is red, with intermediate changes.
- Display the map `Hazclas`.
- Use the `Pixelinfo` to check the result.
- Create annotation for the map `Hazclass` (grid, scale bar, title, legend), and save the result as a map view with the name `Hazclas`.
- Close the map window and the pixel information window.

This ends the first exercise in the creation of a hazard map. In the next exercise you will create a vulnerability map

### 1.3 Creating a vulnerability map

In this exercise you will look at the input data for a vulnerability analysis. The final aim of the exercises at the national scale is to make a qualitative risk map, displaying the areas where there is a high probability that a disaster may occur. For this we also need to know the *vulnerability*: the degree of loss to a given set of elements at risk resulting from the occurrence of the phenomenon. *Elements at risk* are the population, properties, economic activities, etc. at risk within a given area

A vulnerability classification can be carried out in the same way as the method used in the creation of the hazard map: assigning weights to each of the factors, and summing up the weights. The following maps are used for this:

<code>Infraseg</code>	Major infrastructures
<code>Industry</code>	Main industrial centers.
<code>Concentr</code>	Concentration of economic activities.
<code>Popdens</code>	Population density.

The last map `Popdens` does not exist yet. You will first have to create it. This will be done in the first step of the analysis.

#### Creating a population density map

For this calculation you will need the following input data:

- The map `Colombia` from which you can calculate the area of each department.
- A table with the number of inhabitants per department (Table 1.1).

The map is using the following steps:

- First you will calculate the histogram of the map `Colombia`, and find out the area (in square meters) for each department.
- Secondly you will make a table `Colombia` and you join it with the histogram table to obtain the area of each department.
- Thirdly you create a new column `Population` in the table `Colombia`, in which you enter the population numbers per department.
- Then you divide the column `Population` by the column `Area` to find out the population density.
- Finally you reclassify the map `Colombia` with the column `Popdens` and create the population density map.



- Calculate the histogram for the raster map `Colombia`.
- Create a new table, `Colombia`, with the domain `Colombia`.
- In the table window, read in the areas of the department by executing the following formula:  
`Area=Colombia.his.Area`  
Accept the default values.
- Create a column `Population` (type= `Value`, with a range 0 to 6000000, and precision 1).
- Fill in the values from the table below.

Table 1.1: Number of inhabitants per department.

Department	Population
Amazonas	43020
Antioquia	3888067
Arauca	224050
Atlantico	1428601
Bolivar	1197623
Boyaca	1097600
Caldas	838094
Caqueta	214473
Casanare	56014
Cauca	795800
Cesar	58463
Choco	282800
Cordoba	913636
Cundinamarca	5365341
Guainia	10755
Guaviare	21510
Huila	647756
La Guajira	255310
Magdalena	769141
Meta	412300
Narino	1019100
Norte de Santander	883900
Putumayo	56014
Quindio	377860
Risaralda	625451
Santander	1438200
Sucre	529059
Tolima	1051852
Valle de Cauca	2847100
Vaupes	10755
Vichada	21510
Sea	0
Surrounding countries	0



- After entering the values, calculate a column Popdens (population density = number of persons per km<sup>2</sup>). Note that the values in the column Area in m<sup>2</sup>.
- Close the table window.

### Creating the vulnerability map

In the same way as the preparation of the weight maps, used for the hazard map, a series of weight maps should be created to produce a vulnerability map. The weight values, which will be used in this exercise, are based upon the relative importance of each of the elements at risk with respect to the damage caused by a disaster. In reality these vulnerability values will be different for different hazard types. For example: the vulnerability of roads is less for inundations than it is for landslides or earthquakes, as during a flood the roads cannot be used temporarily, whereas during landslides or earthquakes they may be (partly) destroyed. We have not taken this aspect into account here.

The following weight values are used:

#### Concentr

Legend	Weight
high	5
low	0

#### Industry

Legend	Weight
Pipeline	8
No vulnerability	0
1st order industrial center	10
2nd order industrial center	7

#### Infraseg

Legend	Weight
City	10
Main road	8
Railway	8
Road	4
No vulnerability	0

#### Popdens

Legend	Weight
< 1 person/km <sup>2</sup>	0
1-20 persons/km <sup>2</sup>	3
20-50 persons/km <sup>2</sup>	7
>50 persons/km <sup>2</sup>	10

Since the calculation of the vulnerability map is very similar to the one of the hazard map, not all individual steps are explained in detail. All steps are combined below.



- Create tables for the maps Industry, Concentr, and Infraseg, and fill in the weights.
- Create weight maps using the maps Industry, Concentr, and Infraseg, and the tables you have just made. The resulting maps are called Windustr, Wconcent, and Winfras.
- Create weights for population density in the table Colombia using the values in the table on the previous page.
- Create the weight map Wpopdens by reclassifying the map Colombia with the reclassified population densities.
- Combine the four weight maps Windustr, Wconcent, Winfrase, and Wpopdens by adding them up. The resulting map is called Vulnerab.
- Create a class/group domain Vulclas with 4 classes (Very low vulnerability, Low vulnerability, Moderate vulnerability, High vulnerability).
- Classify the map Vulnerab into 4 classes using the operation slicing The result is called Vulclas .
- Display the result and make a representation, and annotation.

At this point you have a hazard map and a vulnerability map, and now you can combine them into the final risk map.

### 1.4 Creating the risk map

The final stage in a risk analysis is the creation of a risk map. According to Varnes (1984), *risk* can be defined as “ *the expected degree of loss due to particular natural phenomena*”. In a real project this would be the multiplication of costs\* vulnerability\*recurrence interval of natural damaging phenomenon. We do not dispose of cost data, and neither of recurrence intervals in this simple example.

Therefore you will simplify the procedure by calculating the risk as the combination of natural hazard and the vulnerability. You will make a qualitative risk map, giving the general relation between hazard and vulnerability. The combination will be done using a two-dimensional table.



- In the Main window, select File, Create, Create 2 Dimensional Table.

- Enter the Table Name `Risk`. Select `Hazclas` as the Primary domain, and `Vulclas` as the Secondary domain.
- Press the Create button next to the Domain list box. The Create Domain dialog box is opened. Create a class domain: `Risk`, with three classes (`Low risk`, `Moderate risk`, and `High risk`). Close the domain editor, and click OK in the Create 2 Dimensional Table dialog box.

The 2 dimensional table is opened. It will contain undefined values for all combinations. Below we have already filled in some of them, for example:

- When the hazard is very low, it doesn't matter whether the vulnerability is low or high; the risk will be low in all cases.
- When the vulnerability is very low (meaning that the area doesn't contain any important elements at risk), the risk is always low.

		Vulnerability			
		Very low	Low	moderate	High
Hazard	Very low	Low	Low	Low	Low
	Low	Low	?	?	?
	moderate	Low	?	?	?
	High	Low	?	?	?
	Very high	Low	?	?	High



- Fill in the missing classes in the two dimensional table above. Give the reason for assigning the risk classes high, medium or low risk.
- Click the upper left field in the 2-dimensional table. Edit the fields using the left arrow ( $\leftarrow$ ). Press the down arrow ( $\downarrow$ ) to go to the next field. Fill in the entire table. It is faster to work with the arrow key, than to click each field, select the right name from the list box, and click another field. You only have to click the upper field of the next column when you are finished with the last field of the previous column.
- When you are finished, close the table window.

The two-dimensional table is now complete. We can use it in a calculation on the command line. The calculation formula should have the following syntax:

Output map = Two-dim table [Map1, Map2]



- Type the following formula on the command line of the main window:  
`Risk=Risk[Hazclas,Vulclas]`
- Press Enter. The raster Map Definition dialog box is opened. Click OK.
- Open the map *Risk* and check its contents.
- Close the map window.
- Create annotation for the map *Risk*.

The creation of a risk map is not the final step in a disaster management. It is merely a tool which has to be used by decision makers in the planning process. One of the politically important aspects is the percentage of each department, with high, medium or low risk. These percentages will be calculated in this section.



- Cross the maps *Colombia* and *Risk* and create a cross table.
- Open the cross table and type the following formula on the command line:  
`High:=iff(Risk="High",Npix,0)`
- Also calculate the columns *Medium* and *Low* in the same way.
- Close the cross table and open the table *Colombia*. Use join operation to read in the maximum value of the columns *High*, *Medium* and *Low* of the cross table. Use table join again to obtain the sum of the column *Npix* from the cross table. Calculate the percentages of each department with high, medium and low risk.
- Find the five most endangered departments of Colombia (the ones with highest percentage of their area classified as high risk).

Nr	Department	Percentage high risk

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