CHAPTER 7

Seismic landslide hazard zonation

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Summary

This exercise is intended to show the potential of GIS in regional hazard zonation of landslides triggered by earthquakes. This exercise is based on data from Manizales (Colombia) which were collected in the framework of the ITC-UNESCO project on the use of GIS for mountain hazard mapping in the Andean environment.

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap07. 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\chap07. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).

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- 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\chap07.

Now you are ready to start the exercises of this case study.

7.1 Available data

In this exercise a regional landslide hazard map will be prepared for an earthquake with a magnitude of 6.3 on the Richter scale which may occur close to Manizales. Geological studies have shown that a seismotectonic zone exists approximately 15 km north of Manizales capable of generating earthquakes with depths of 10 to 13 km and magnitudes over 6 on the Richter scale (Valencia, 1988).

On the basis of the regional geomorphologic map which combines information on rock types, soil types and slopes, a susceptibility map for seismically-induced landslides will be created. A polygon map `Geomani` of the regional geomorphologic setting of the Manizales is provided. Since this exercise is only intended to show the potential of using GIS in seismic landslide hazard zonation and not to prepare an accurate hazard map to be used for planning purposes, the geomorphologic and seismological setting are highly simplified.

7.2 Methodology

The landslide types that are triggered by earthquakes can roughly be classified into three groups (Keefer, 1984):

- Rock falls and disrupted soil slides.
- Coherent deep-seated slumps.
- Lateral spreads.

Given the geomorphologic setting of Manizales landslides of type I and type II are most likely to be triggered by earthquakes.

Rock falls are mainly found in closely jointed or weakly cemented rocks. Steep slopes in loose, residual or colluvial materials with low cohesion are susceptible to disrupted soil slides. Coherent deep-seated, mostly rotational soil slumps are often found in relatively flat zones in deposits with significant cohesion.

Arias intensity is defined as the sum of all the squared acceleration values from seismic strong motion records. Arias intensity has been found to be a fairly reliable parameter to describe earthquake shaking necessary to trigger landslides. Researchers in California (Harp and Wilson, 1995) found a minimum Arias intensity of 0.11 m/s for the initiation of landslides of type I. The same authors reported a minimum Arias intensity of 0.32 m/s required for the initiation of landslides of type II. The larger Arias intensity indicates that stronger and longer-duration shaking is required to trigger landslides of type II.

In order to prepare a simple regional hazard zonation map which indicates where an earthquake with a certain magnitude could trigger landslides of type I or type II around Manizales, the following two input maps have to be created:

(2)   A map which shows the Arias intensity that can be expected at a specific site, with a given earthquake magnitude, earthquake depth and distance from earthquake's epicenter.

(3)   A map which shows the minimum Arias intensity required to initiate a landslide (which is a function of the geomorphologic terrain conditions, that decide whether the terrain is susceptible to landslides of type I or type II).

At those sites where the expected Arias intensity exceeds the minimum required Arias intensity, landslides may be triggered.

7.3 Epicenter map

For the calculation of the spatial distribution of Arias intensity an attenuation law which gives Arias intensity as a function of earthquake magnitude, earthquake depth and distance to earthquake epicenter will have to be selected. In this case study the attenuation law of Wilson and Keefer (1985) based on California earthquake data is used:

$$\text{Log}_{10}\text{I}_a = -4.1 + \text{M}_w - 2\text{Log}_{10}(\text{d}^2 + \text{h}^2)^{0.5} - 0.5\text{P} \qquad [7.1]$$

in which:

$\text{I}_a =$ Arias intensity (m/s).

$\text{M}_w =$ Moment magnitude.

$\text{d} =$ Closest distance to surface projection of fault rupture (km).

$\text{h} =$ Focal depth of earthquake (km).

$\text{P} =$ Probability of exceedance.

For the preparation of the Arias intensity map a point map with the location of the epicenter is required. The local coordinate system of the geomorphologic map will be used as georeference. In this exercise   a hazard map is prepared for an earthquake with a magnitude of 6.3, located within the seismotectonic zone north of Manizales with the following epicenter coordinates: x = 1172000, y = 1064000.

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- Select from the menu items File, Create, Create point map. Give
  `Epicentr` as map name.
  Select for coordinate system Unknown. Give minimum x- and y-coordinates slightly smaller than the epicenter coordinates. Give maximum x- and y-coordinates slightly larger than epicenter coordinates.

- Create a new domain called `Epicentr`. Select type Identifier. Close the domain editor.

- When leaving Create point map dialog box, the point map editor is started.

- From the menu options select Edit, Add point to add the coordinates of the epicenter and give it the name `Epicentr`.

- Quit the point map editor.

7.4 Rasterizing and reclassifying the geomorphologic map

The available geomorphologic map `Geomani` is a polygon map that has to be rasterized.

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- Display the map `Geomani` by double clicking its icon and accepting the default values.

- Quit the map display by selecting Exit.

- Press the right mouse button on map `Geomani` and select Polygon to Raster and give `Geomani` as the output map name.

- Create a new georeference with the name `Geomani`. Select for coordinate system Unknown. Use a pixel size of 20 m.

  Use the following coordinates:

  $x_{min} = 1170800$ $y_{min} = 1049100$
  $x_{max} = 1177750$ $y_{max} = 1054000$

- Click OK. You are now in the Rasterize Polygon Map dialog box. Click OK.

The geomorphologic map has to be reclassified into two classes indicating the susceptibility of the terrain to landslides of either type I or type II. A description of each unit is found in the table below. The units characterized by steep slopes and thin soils are mainly susceptible to landslides of type I. while more gentle slopes with a thick soil cover are susceptible to deep-seated landslides of type II.

Table 7.1: Geomorphologic units in the area

Geological unit	Description	Landslide type
Qp	Gentle slopes (<15°) in thick (>10 m) pyroclastic fall deposits	2
Qa	Recent alluvial deposits	No landslides
Qt	Recent alluvial and fluvio-volcanic terraces	2
Qc	Colluvial deposits related to fault activity	2
Qb	Steep slopes on basaltic intrusion	1
Tcb	Steep slopes in weathered alluvial and fluvio-volcanic deposits	1
Tmz	Steep slopes in conglomerates and pyroclastic flow deposits	1
Kq	Steep slopes in meta-sedimentary schist with thin (<5 m) cover of pyroclastic fall deposits	1
Ki	Steep slopes in intrusive gabbros	1

This table has to be prepared in GIS and subsequently linked to the geological map.

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- Create the table `Suscept` with the domain `Geomani`. Click OK. The table `Suscept` is now open. Select from the menu Column, Add columns to add the column `Lstype` and create a domain of Class type with the following values:

Code	Name
0	No slides
1	Type I
2	Type II

- Enter the values from the column "landslide type" from the table 7.1 in the column `Lstype` and save the table. Close the table.

- Link the table `Suscept` to the geological map by selecting Properties, Attribute table from the menu Edit of the `Geomani` map.

- Create the attribute map `Suscept` by selecting Operations, Raster operations, Attribute map from the menu Edit of the `Geomani` map. Use the attribute `Lstype` from the table `Suscept`.

- Display the map `Suscept` and check by using PixelInfo whether reclassification has been executed correctly.

7.5 Preparing and classifying the Arias intensity map

The first step in preparing the Arias intensity map is the rasterization of the map with the epicenter north of Manizales.

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- Press the right mouse button on map Epicentr and select
  Rasterize, Point to Raster from the context sensitive menu.

  Use a pixel size of 20 m.

- Give the raster map the same name as the point map. Use a point
  size of 1 and create a georeference called Epicentr. Use the
  following coordinates:

  x_{min} = 1170800 y_{min} = 1049100
  x_{max} = 1177750 y_{max} = 1065200

As a second step the distance to the epicenter has to be calculated for each pixel.

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- Press the right mouse button on raster map Epicentr and select
  from the context sensitive menu Raster operations, Distance.

- Create a distance map with the name Dist, use the domain
  Distance. Don't use a weight map and don't make a Thiessen map.

The map Dist is much larger than the map Geomani. Therefore, a sub map has
to be created from the former.

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- Press the right mouse button on map Dist and select the Sub map
  function of the sensitive context menu and create the map Epidist
  with the following dimensions:
  First line: 561
  First column: 1
  Number of lines: 246
  Number of columns: 349

- Break dependency link of the map Epidist and change the
  georeference to Geomani.

Finally the attenuation law has to be applied to obtain the spatial distribution of
Arias intensity for an earthquake with magnitude 6.3. For the preparation of the
Arias intensity map the following data are used:

Moment magnitude =   6.3
Focal depth of earthquake (km) =   10 km
Distance to epicenter (km) =   Epidistk map
Probability of exceedance =   0.5

Before the attenuation law can be applied the `Epidist` map has to be converted from meters into kilometers

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- Type the following command on the command line:

  `Epidistk=Epidist/1000↵`

  The precision is `0.01` and the range `9-17`.

- Create a map `Logai` by typing the formula:

  `Logai=-4.1+6.3-2*log(hyp(Epidistk,10))-0.25↵`

  The precision is `0.001` and the range `-0.7--0.2`

- Type the following commands on the command line to calculate the Arias intensity map:

  `Ai=pow(10,Logai)↵`

  The precision is `0.001` and the range `0-1`.

- Display the map `Ai` and check whether the values vary from approximately `0.4` in the northern part of the area (closer to the epicenter) to `0.25` in the southern part of area.

The Arias intensity map has to be classified into the following three classes according to the type of landslide which can be triggered:

Table 7.2: Types of landslide according to the Arias intensity

Class	Arias intensity	Landslide type
1	<0.11 m/s	No landslides
2	0.11 - 0.32 m/s	Type I
3	> 0.32 m/s	Type I and II

A group domain has to be created for the classification of the Arias intensity map This group domain contains the boundaries of the three Arias intensity classes.

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- Create the domain `Aiclass`; select Class and Group and continue by choosing OK. Add the following items:

Upper bound	Class
0.11	1
0.32	2
1	3

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- Type the following command on the command line to classify the Arias intensity map:

  ```
  Aiclass=clfy(Ai,Aiclass)↵
  ```

- Display the map `Aiclass` and check by using pixel information whether classification has been executed correctly.

7.6 Preparing seismic landslide hazard zonation map

The seismic landslide susceptibility map and the classified Arias intensity map have to be combined in order to prepare a map which shows the zones that can be affected by landslides of type I and type II during an earthquake with a magnitude of 6.3 north of Manizales. The final map will consist of the following three classes:

Class 1:   No landslide hazard
Class 2:   Hazard for landslides of type I
Class 3:   Hazard for landslides of type II

The classes are obtained by the following combinations of classes from the seismic landslide susceptibility map `Suscept` and the classified Arias intensity map `Aiclass`.

Table 7.3: Possible combinations of seismic landslide susceptibility and the classified Arias intensities

		Arias intensity map		
		Class 1	Class 2	Class 3
Seismic landslide susceptibility map	Class 0	1	1	1
	Class 1	1	2	2
	Class 2	1	1	3

In ILWIS the two maps can be combined in several way. In this example a cross table is used.

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- Cross the maps `Suscept` (first map) and `Aiclass` (second map).

  Create and output table with the name `Crosstab` and an output map with the name `Crossmap`.

- Open the cross table `Crosstab` and add a column with the name `Final`; create a class domain `Final` such as:

> | Code | Class |
> |------|-------|
> | 1 | No hazard |
> | 2 | Hazard for landslide of type I |
> | 3 | Hazard for landslide of type II |
>
> The domain of `Crosstab` consists of the different combinations of `Suscept` and `Aiclass`. Fill the column final according to the reclassification table given above and exit the table.
>
> - Link the table `Crosstab` to the map `Crossmap` to create the attribute map `Final`. Use the attribute `Final`.
>
> - Display the map `Final` and check by using PixelInfo whether reclassification has been executed correctly.

The final map should show the following zones:

1. Zones where there is no landslide hazard either because the terrain is not susceptible to landslides or because the Arias intensity is not large enough to trigger landslides.
2. Zones with a hazard for landslides of type I.
3. Zones with a hazard for landslides of type II.

This simple hazard map for earthquake-triggered landslides can serve as a base map for a more detailed study in which additional maps such as a slope map, a hydrogeological map and a surface deposits map have to be used. In order to create a risk map also data about infrastructure, buildings and economic activity of the region have to be included.

References

Harp. E.L. and R.C. Wilson. (1995). Shaking intensity thresholds for rock falls and slides: Evidence from the 1987 Whittier Narrows and Superstition Hills earthquake strong motion records. *Bulletin of the Seismological Society of America*, 85 (6): 1739-1757.

Keefer, D.K. (1984). Landslides caused by earthquakes. *Geol. Soc. Am. Bull.*, 95: 406-421.

Valencia, C.E. (1988). *Geotectónica regional del antiguo Caldas con énfasis en la aplicación a la ingeniería sísmica*. Unpublished Msc. Thesis, Universidad de los Andes, Bogotá, Colombia, 54 pp.

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