GISSIZ: Geographic Information Systems In Slope Instability Zonation. Case study of the Kakany area, Nepal

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CHAPTER 1

Introduction to the project

Objectives

GIS can be used very effectively for landslide hazard zonation at medium-scales of 1:25,000 to 1:50,000. The study area is relatively small, so that sufficient data can be collected. Most of the methods for landslide hazard zonation (treated in volume 1 of the GISSIZ package), can be applied at this scale. In this case study you will become more familiar with a number of them.

The various methods are all applied to a data set from a study area in Nepal: the Kakani area, located NW of Kathmandu in Nepal. Most of the maps needed for this case study are already available. They are derived from four 1:10,000 scale thematic maps and a series of articles, which are included as part of the case study materials.

This case study not only deals with GIS. You will also interpret the airphotos of the study area, and compare your interpretation with the paper maps. Furthermore you are requested to update the maps and create some new ones, which you have to digitize and include in the database.

The GIS exercises are not in a "cookbook" format. You will have to find out the exact way yourself, since the exercises will only give you general guidelines.

The exercises that you are going to do have the following objectives:

− To give you an understanding of the various phases needed in a landslide hazard zonation project
− To allow you to study the terrain conditions in a study area in the Himalyan environment, and understand the factors involved in the occurrence of landslides.
− To make you familiar with the various input maps needed for a landslide hazard zonation, and how they are derived
− To let you practice your skills in using the ILWIS GIS for different types of landslide hazard zonation techniques, such as:
  - landslide distribution analysis, landslide activity analysis, landslide density analysis
  - qualitative landslide hazard analysis
  - bivariate statistical analysis
  - deterministic landslide hazard analysis
The Kakani area

The Kakani area is situated in the upper Kolpu Khola watershed, NW of Kathmandu in Nepal. The study area occupies about 21.5 square km. The area with its relatively dense population (Kienholz et. al. 1983 estimate about 270 inhabitants/sqkm), intensive agricultural use and severe mountain hazard problems is representative for many parts in the Nepalese Middle Mountain Belt. In the last two decades this region was subject of several investigation programs; concerning hydrology, geology, slope stability and mountain hazard mapping.

Above all the area is characterized by a very pronounced denudational relief reaching from 1100m to 2300m asl., its dense drainage network and steep slopes.

The lithologic units are predominately east-west striking with steep almost vertical dips between 80 to 90 degrees (Peters & Mool 1983). The northern part is underlain by relatively resistant gneisses and augen-gneisses, the center by less resistant biotit-gneisses and the south by easily weathering quartzites and phyllites. The structural unity is disturbed by a granitic intrusion with tourmalin and pegmatite dykes.

Precipitation is dominated by the monsoonal circle with pronounced rainy and dry season. After Cain 1980 eighty percent of total precipitation falls between June and end of September; the total yearly amount of rainfall is about 2400mm at the Kakani Hill Station. The combination of low resistant rocks with the climatic conditions results in deep weathering of the substrats of the Kakani Area. The soils are quite fertile.

The population is primarily dependent on subsistence agriculture. Most of the land is used for farming; due to the steep slopes the majority of the parcels are terraces. Either for rain fed crops or irrigated agriculture. Gullies, slumps and landslides occur throughout the entire area; affecting both rain fed and irrigated terraces. In areas with rain fed terraces actually erosional processes produce badlands. Also the vicinity of irrigation channels is frequently affected by erosional damage and landslides. These processes result mainly in loss of soil and arable land which will cause significant reduction of agricultural production. In some locations even houses, cattle and people are endangered by denudational processes.

The causes of this high degree of instability for the Nepalese Middle Mountains were summarized by Kienholz with the following key words:

- Middle Hills, the favourable agricultural zone of Nepal.
- Population pressure
- Accelerated deforestation
- Increased surface runoff
- Increased erosion
- Loss of arable land
- Cultivation of marginal areas

The heavily disturbed areas are mainly situated on slopes with rain fed terraces or unfavourable conditions. Whereas on well situated terraces especially or irrigated parcels, a better cost benefit ratio enables the farmers to reclaim damaged areas or to repair slumped terraces.
Literature

Apart from these four maps, a number of papers concerning the project are available. The following papers are attached in a separate reader:

**Bosshart, U. (1993)**

**Caine, N. and Mool, P.K. (1981)**
Channel geometry and flow estimates for two small mountain streams in the Middle Hills, Nepal. Mountain Research and Development, Vol. 1, No. 3-4, pp. 231-243

**Caine, N. and Mool, P.K. (1982)**

**Frei, E.**

**Ives, J. and Messerli, B. (1981)**


**Kienholz, H. Hafner, H. and Schneider, G (1984)**


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- Study the papers listed above, and make a small summary in which you characterize the study area, with respect to:
  - the location
  - the geology
  - the landslide and erosion processes
  - the landuse and population
  - the hazard assessment

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Background information on landslides, and landslide hazard zonation, can be found in the following books:
GISSIZ: GIS in Slope Instability Zonation

Crozier, M.J. (1986)
Landslides: causes, consequences & environment


Strategies for classification of landslides

Rib, H.T. and Liang, T. (1978)
Recognition and identification.

Selby, M.J. (1982)
Hillslope materials and processes.


ITC-Publication Number 15, ITC, Enschede, The Netherlands

Varnes, D.J. (1978)
Landslide types and processes.

Varnes, D.J. (1984)
Landslide Hazard Zonation: a review of principles and practice
Commission on Landslides of the IAEG, UNESCO, Natural Hazards No 3, 61 pp.

Other specific literature on landslide hazard zonation in the Hindu Kush Himalaya:

Landslide hazard management and control in the Hindu Kush-Himalayas. ICIMOD publication, Kathmandu, Nepal. 41 pp

Mountain risk engineering handbook. ICIMOD publication. Volume 1&2, 875 pp, ICIMOD, Kathmandu, Nepal

Deoja, B. (1994)

The role of extreme weather events, mass movements, and land use changes in increasing Natural Hazards. ICIMOD report, ICIMOD Kathmandu, Nepal, 123 pp.

Li Tianchi (1996)
Landslide Studies and Management in China. ICIMOD publication, Kathmandu, Nepal, 36pp

Malik, M.H. and S. Farooq (1996)
Landslide Studies and Management in Pakistan. A Review. ICIMOD publication, Kathmandu, Nepal, 68pp

Messerli, B., Hofer, T. and Wymann (eds)
Himalayan Environment. Pressure-Problems-Processes. Geographica Bernensia, G38, University of Bern, Switzerland, 206 pp

Sharma, C.K. (1977)
Landslides and soil erosion in Nepal. 93 pp.

Thakur, V.C. (1996)
Landslide Studies and Management in India. ICIMOD publication, Kathmandu, Nepal, 68pp

WECS (1987)
Erosion and sedimentation in Nepal. Water and Energy Commission, Ministry of water resources, Nepal,

Landslide Studies and Management in Nepal. ICIMOD publication, Kathmandu, Nepal, 87pp
EXERCISES on photo-interpretation: Kakani area (Nepal)

Two series of airphotos are available for the Kakani study area:
- 1:50.000 scale airphotos, covering the Western part of Kathmandu valley and the Kakani study area
- 1:12.000 scale airphotos covering the northern part of the Kakani study area

Please make the following interpretations:
- Landslide interpretation, using the photo-checklist given below, and comparing the interpretation with the Map No 2: Geomorphic damage map. The interpretation should be done on the central photo of the 1:10000 scale series
- Landuse interpretation, including infrastructure and housing, by comparing map no 1: Landuse map and map no 3: Base Map. This should also be done on the central photo of the 1:10.000 scale series.
- Interpretation of faults. This map is still missing in the data base. No information is available on faults in the area. This should be done on the 1:50.000 scale photo covering the entire Kakani study area.

The photo-checklist is shown below:

<table>
<thead>
<tr>
<th>Nr</th>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slide</td>
<td>Planar</td>
<td>Active</td>
<td>Surficial (&lt;5m)</td>
<td>clastic material</td>
<td>scarp</td>
</tr>
<tr>
<td>2</td>
<td>Flow</td>
<td>Sharp</td>
<td>Not active</td>
<td>Deep (&gt;5m)</td>
<td>weathered rock</td>
<td>body</td>
</tr>
<tr>
<td>3</td>
<td>Fall</td>
<td>Slow mass movement</td>
<td></td>
<td></td>
<td>fresh rock</td>
<td></td>
</tr>
</tbody>
</table>
EXERCISE 1

Evaluating the digital data

Available data
The basic data were derived from maps, prepared in the framework of the Mountain Hazards Mapping Project of the Nepal National Committee for UNESCO (National Committee for the Man and the Biosphere [MAB] Programme), the United Nations University (Highland-Lowland Interactive Systems Project), the University of Berne (Switzerland), the University of Colorado (Boulder, Colorado, USA), and Clark University (Worcester, MA, USA). Aim of this project was the production of prototype maps to show slope stability and mountain hazards in Nepal and the development of corresponding methods for assessing mountain hazards. The project leaders were DR. H. Kienholz, Dr. J. Ives, and Dr. B. Messerli.

In the framework of this project a series of maps were made for the Kathmandu-Kakani area, at scale 1:10,000, based on the topographic Base Maps of the "Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung, Munich", the so-called "Schneider-maps". The following maps were used in this case study:

- Map 1: Landuse Map
- Map 2: Geomorphological damage map
- Map 3: Base map
- Map 4: Mountain hazards and Slope Stability.

Besides of these maps you will also make use of a set of aerial photos.

For this case study the information from the 4 maps was digitized and a data base was created in ILWIS 2.1. Due to the different requirements of a GIS legends had to be modified, and the information from some maps had to be stored into different data layers.
Map 1: The Base map

The first map is called “base map”. The thematic information on this map containing a summary of damaging processes, landuse and human activity, was not digitized, since it could also be obtained by the combination of other maps. This will be done in a later exercise. From this map the following features were digitized:

Elevation data:

The basic data concerning elevation is a vector file with digital contour data, obtained by digitizing the contour lines from the 1:10.000 topographic map, especially made for the MAB project, with intervals of 10 meters. The result was stored in the segments map: cont10. In a later exercise you will use this map to generate a Digital Elevation Model, and derivative maps such as slope angle and slope direction maps.

- Display the segment map cont10 and check the altitude values.
- Calculate the histogram of the map cont10 and find out the contour-interval.

Geology:

The geological information of the area is very basic. Only a 1:50.000 scale onset map printed within the legend of the base map was available, and the geological boundaries were drawn in the base map.

The following rock units were recognized in the Kakani area:
- Biotitegneiss,
- Augengneiss,
- Gneiss,
- Quartzitic-phyllites
- Quartzites
- Tourmaline-muskovite-Granite
- Tourmaline-Muscovite Pegmatite.

The differences in resistance to weathering has a great influence on slope stability and topography. The quartzites-phyllites are due to their high contents of albitic plagioclase the most vulnerable to weathering followed by the biotitegneisses and granites. The most resistant rocks in the Kakani area are the gneisses. The combination of the almost vertical dipping schistosity, deep weathering and the steep slopes is apart from the increasing antrophogenic "pressure" one of the main parameters of slope stability in the Kakani area.

The units were digitized and the resulting polygon map is called: geology. Fault information is not available.

- Display the polygon map geology, together with the segment map cont10 and check the meaning of the units.

Roads:

The roads in the area (the paved road, connecting Kathmandu and Trisuli, unpaved roads, and footpaths) were digitized from the 1:10.000 scale base map. The result was stored in the segment map: road.
Display the segment map road on top of the maps geology and cont10 and check the meaning of the lines.

Calculate the length of the different types of roads using the histogram.

**Powerline:**

The electrical powerline is digitized from the toponmap, and the location of the towers is stored in a point map (powpylon). The resulting segment map is called: powerline.

Display the segment map powerline on top of the maps geology, cont10, and road and check the meaning of the lines.

Add the point map powpylon to the map window.

**Population.**

The houses and other buildings were digitized from the 1:10.000 scale base map, and stored as a point map (houses).

The ethnic distribution of the population was digitized after the sketch map of Mool from the paper by Kienholz, H., Hafner, H., Schneider, G. and Tamrakar, R. (1983). The result was stored in a polygon map called: ethnic.

Display the polygon map ethnic on top of the maps cont10, and road and check the meaning of the units.

Calculate the area occupied by each of the ethnic groups. Write the results in the table below.

Calculate the percentage of the total area. Write the results in the table below.

Add the point map houses to the map window.

Open the point map houses as table, and calculate for each house to which ethnic group its occupants belong, using the Mapvalue function.

Calculate the number of houses per ethnic group. Write the results in the table below.

Calculate the density of houses for each ethnic group. Write the results in the table.

Which ethnic groups have the highest population density?

<table>
<thead>
<tr>
<th>Ethnic group</th>
<th>Area (in sq. km²)</th>
<th>Percentage of area</th>
<th>Number of houses</th>
<th>Nr houses/km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brahmin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brahmin and Chatri</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newari-Balami</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newari-mixed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newari-Salmi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamang</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working class</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rainfall

Some very general rainfall data was available from the paper by Kienholz, H., Hafner, H., Schneider, G. and Tamrakar, R. (1983). The isohyets (lines of equal average annual rainfall) were digitized and stored in the segment map Rain.

- Display the segment map rain using the Pseudo representation.
- Add the segment map cont10 using a gray representation.
- What is the relation between rainfall and altitude in the area?

Measured landslides.

The base map contains 16 points indicated as "locations of Geomorphological analysis". These points are described in the paper by Kienholz, H., Hafner, H., Schneider, G. and Tamrakar, R. (1983), and in the paper by Caine, N. and Mool, P.K. (1982). The points are stored in a point map called slidedat, which has an attribute table, called slidedat. This table contains the results of investigation of 16 landslides within the study area, with their location, landslide type, age, length, width and depth. Since the codes used for the landslides in both papers are different, the table also contains the codes according to Kienholz et al (1983) and according to Caine and Mool (1982).

- Display the point map slidedat together with the segment map cont10, using the Pseudo representation.
- Double-click on the point to read the attribute information.
- Close the map window when finished.
Map 2: The landuse map

The second paper map of the Kakani area that you have at your disposal is the landuse map. From this map the landuse polygons were digitized. The legend of the digital map was slightly generalized, since the original map contained too many mixed landuse units. The resulting polygon file is called landuse. The following legend units were made:

**Irrigable terraces (Khet)**

The terraces are flat and enclosed to the valley side by a mud wall to retain the irrigation water. During the rainy season mainly rainwater is used for irrigation. Water is channeled from streams and rivers during the dry season. Crop rotation consists of rice and wheat. Particularly while the rice is growing the ground must be covered by 3-5cm of water. Wheat is irrigated about three times; each time for one day. The entire irrigable area is cultivated year-round except for a few marginal terraces which are left fallow in winter. The irrigable fields produce the highest yield of all the cultivated land, they are most often found in the lower catchment areas.

**Non-irrigable terraces (Bari)**

The crops which grow on this type of parcels obtain their moisture only from precipitation. The terraces are sloping to enable excess rainwater to drain off. The main crops are corn, millet and buckwheat (also barley, potatoes, radishes, mustard, beans). Almost all of the rain-fed terraces are left fallow for about two months during the dry season. This type of farming is found mainly in the upper catchment areas. Settlements and some of the roads have also been included in this category of landuse.

**Idle terraces**

Idle terraces are characterized by their deteriorating structure, sometimes after being fallow for a certain period they can be cultivated again. Idle terraces are usually used for grazing and shrubs frequently take root. Non-irrigable terraces are left more often idle than irrigable ones.

**Grassland and pasture**

The mayor part of the grassland is pasture. Due to the large cattle population in relation to the available grazing land, the pastures are often subject to overgrazing which leads to erosion. Usually grazing is unregulated. This land use type is characterized by small scattered plots and is often found in combination with other types of land use.

**Barren land**

Barren land is largely devoid of grass and lacks a layer of humus making farming impossible. Such areas almost always occur in connection with erosion. Most of the barren land is the result of large landslides and human influences such as road-building, bad irrigation management and overgrazing.

**Shrubland**

Areas covered with vegetation up to a height of 3m have been surveyed as shrubland. Shrubland is above all the result from forest degradation. It is found mostly along the periphery of the Tareswar Forest. As well as being used sometimes as pasture, shrubland is a source of fuel-wood and, during the dry season, of fodder.

**Deciduous or Coniferous forest**

Lofty primary forest is only found scarcely, most of the wooded areas have already been thinned out, some heavily as a result of exploitation. The forests are a source of fuel-wood and timber. Sometimes they are also used for grazing and for fodder. Additional stands of trees, mainly serving as protective barrier, are found along steep ravines.

**Riverbed**

The active, unvegetated riverbeds were grouped in this unit

**Terrace mixed irrigable and non irrigable**

If the mixed landuse units on the original map contained a combination with bare land, shrubs or grassland, they were classified as such. Therefore this unit mostly contains mixed terraces.

- Display the polygon map landuse and compare it with the paper copy.
• Calculate the percentage of each landuse type and store the result in the table below.
• Close the map window when finished.

<table>
<thead>
<tr>
<th>Landuse type</th>
<th>Area in square km</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren land</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland and pastures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riverbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrace (idle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrace (irrigable): Khet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrace (mixed irrigable and non irrigable))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrace (non irrigable): Bari</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Optional:**
Make a photo-interpretation of the available photos of (a part of) the study area, in which you indicate the landuse classes given above. Use the paper map **Map No 1: Land Use** as a reference.
Map 3: The geomorphological damage map

The third of the four paper maps, showing Geomorphic damage, was the most complicated one to digitize. As can be seen from the example of this map, shown on the bottom part of the paper map, the map contains many legend units, of different features. Besides of that the map is composed of symbols, while a useful map for GIS should preferably be composed of polygons. That is why the information from this map was stored in a number of different files:

Hydrography

The classification of natural streams was stored in the segment map rivers. The drainage lines in this map contain 4 codes:
- Bed in balance (balanced alternation of erosion and accumulation)
- Bed with erosion.
- Bed with latent erosion (bed in strong bedrock)
- Not classified (other drainage channels)

The information on wells and springs was stored in the point map springs. The point map contains only two types:
- wells
- springs

Erosion

The information on erosion features was stored in a polygon map erosion. This file contains the following units:
- rillwash
- area with rillwash
- gully active
- gully inactive
- badland active (gullying, slope failure etc.)
- badland inactive
- badland less than 5 meter deep
- badland more than 5 meter deep

Mass movement along creeks and rivers

The information on this was stored in the polygon map mmriv. This file contains the following units:
- Scarp of a slide or slump caused by stream erosion in clastic material
- Scarp of a slide or slump caused by stream erosion in highly weathered bedrock
- Scarp of a slide or slump caused by stream erosion in hardly weathered bedrock
- Scarp of a slide or slump caused by stream erosion with vegetation

Mass movement on open slopes

The information on this was stored in the polygon map slide. This file contains the following units:
- Scarp of a slide or slump in clastic material
- Scarp of a slide or slump in highly weathered bedrock
- Scarp of a slide or slump in hardly weathered bedrock
- Scarp of a slide or slump with vegetation
- Planar slide in clastic material without vegetation
- Planar slide in clastic material partially with vegetation
- Planar slide in clastic material with vegetation
- Planar slide in bedrock
- Rockwall fresh and continuous
- Rockwall interrupted by slopes covered with vegetation

**Slow mass movements**

The information on this was stored in the polygon map: `slow`. This file contains the following units:

- Confirmed slow mass movement (undefined)
- Confirmed slow mass movement (shallow <2 meter)
- Confirmed slow mass movement (deep > 2 meter)
- Presumed slow mass movement (shallow <2 meter)
- Presumed slow mass movement (deep > 2 meter)

**Other elements of erosion**

The information on this was stored in the polygon map: `other`. This file contains the following units:

- Tensile crack
- Damaged irrigable terrace
- Damaged non-irrigable terrace
- Damaged vegetal cover

**Deposition**

The information on this was stored in the polygon map: `depo`. This file contains the following units:

- Deposition of slides as compact mass
- Deposition of slides as boulders (fresh)
- Deposition of slides as boulders (partially weathered)
- Deposition of slides as boulders (partially overgrown)
- Deposition of slides as debris flow (fresh)
- Deposition of slides as debris flow (partially overgrown)
- Other deposition

**Man made elements**

The information on this was stored in the polygon map: `man`. This file contains the following units:

- Slope cutting in clastic material
- Slope cutting in highly weathered bedrock
- Slope cutting in hardly weathered bedrock
- Slope cutting with vegetation
- Man-made badland (intended terrace construction)
- Cattle steps
- Defile, sunken path
- Gravel pit
Map 4: The map of Mountain Hazards and Slope Stability.

The last of the 4 paper maps of the Kakani study area is a hazard map. This is a so-called direct-hazard map, made by the expert geomorphologists with the use of checklists. The legend is quite complex.

The map shows the following information ranked by level of detail:

- The degree of hazard indicated by different colors
- Differentiation between direct hazard to life and property and indirect hazard caused by severe soil loss
- Differentiation between direct hazard based on confirmed facts and that based on supposition
- Type of hazard (such as soil erosion or landslide)

Due to the very detailed multi-level legend with its exhausting unit area description (at least five levels of information for every unit area) a new code had to be assigned which meets the demands for polygon names in Ilwis.

In the following you will find a description of the legend's structure and its transformation.

First and second level, the degree of hazard or instability

The first level provides information concerning the confirmed or inferred degree of hazard or instability, by the use of different colors. Reds and browns indicate a high degree of hazard, yellow an intermediate state and green stability. Blue is used for areas affected by torrent activity.

The second level of detail is provided by differentiation within reds and browns according to whether human life and hard structures are endangered (reds) or if the hazard is confined to loss of arable land and soils (browns). See table on the next page for a detailed description and the new code.

Third level of information, suspected higher degree of hazard or instability

If less than 50% of an unit area is suspected to a higher degree of instability the second character of the resulting polygon name (unit code) is "1"; if this is the case for more than 50% the second character is a "2".

Fourth and fifth level of information, type, evidence and corresponding degree of hazard or instability per unit area

The type of hazard is indicated on the map by corresponding letters, such as "E" for deep erosion, "e" for shallow erosion or "e'" for surificial erosion. The evidence is shown by supplements such as "(type-symbol)" or ",_. Since Ilwis uses those symbols as operators they cannot be used as unit-identifiers. For that reason a new code for type and evidence was assigned. The corresponding degree of hazard for each type was not included in the polygon name but you will find it apart from the newly assigned codes in the following table.
<table>
<thead>
<tr>
<th>color</th>
<th>hazard</th>
<th>Effects</th>
<th>New code</th>
</tr>
</thead>
<tbody>
<tr>
<td>green</td>
<td>0</td>
<td>- no known hazard or stable</td>
<td>1</td>
</tr>
<tr>
<td>yellow</td>
<td>1</td>
<td>- buildings, roads or other structures may be damaged</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- arable land may be damaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- moderate amount of soil material may be transported away by the streams</td>
<td></td>
</tr>
<tr>
<td>orange</td>
<td>1&amp;2a</td>
<td>- mosaic of degree 1 and degree 2a</td>
<td>3</td>
</tr>
<tr>
<td>light brown</td>
<td>1&amp;2b</td>
<td>- mosaic of degree 1 and degree 2b</td>
<td>4</td>
</tr>
<tr>
<td>red</td>
<td>2a</td>
<td>- human lives are endangered even in houses</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- buildings, roads or other structures may be destroyed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- arable land may be irreversibly destroyed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- medium to high amount of soil material may be transported away by the streams</td>
<td></td>
</tr>
<tr>
<td>brown</td>
<td>2b</td>
<td>- buildings, roads or other structures may be damaged</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- arable land may be irreversibly destroyed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- medium to high amount of soil material may be transported away by the streams</td>
<td></td>
</tr>
<tr>
<td>reddish brown</td>
<td>2a&amp;2b</td>
<td>- mosaic of degree 2a and degree 2b</td>
<td>7</td>
</tr>
<tr>
<td>darkblue</td>
<td>2a</td>
<td>- torrent activity (effects see degree 2a)</td>
<td>8</td>
</tr>
<tr>
<td>light blue</td>
<td>1</td>
<td>- no or little torrent activity (effects see degree 1)</td>
<td>9</td>
</tr>
<tr>
<td>TYPE OF HAZARD ACCORDING TO THE MAP</td>
<td>NEW CODES FOR TYPE, EVIDENCE AND CORRESPONDING DEGREE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CONFIRMED /INFERRED</strong></td>
<td><strong>SUSPECTED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in: &lt;50% of unit area</td>
<td>in: &gt;50% of unit area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in: &lt;50% of unit area</td>
<td>in: &gt;50% of unit area</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CODE</strong></td>
<td><strong>DEGREE</strong></td>
<td><strong>CODE</strong></td>
<td><strong>DEGREE</strong></td>
</tr>
<tr>
<td>E deep erosion by water (&gt;2m), deep gullies</td>
<td>a</td>
<td>2&amp;5</td>
<td>ad</td>
</tr>
<tr>
<td>e shallow erosion by water (&lt;2m), shallow gullies</td>
<td>b</td>
<td>2&amp;6</td>
<td>bd</td>
</tr>
<tr>
<td>e' surficial erosion, rills</td>
<td>c</td>
<td>1&amp;1(6)</td>
<td>cd</td>
</tr>
<tr>
<td>L deep landslide (&gt;2m)</td>
<td>d</td>
<td>2&amp;5</td>
<td>ed</td>
</tr>
<tr>
<td>l shallow landslide (&lt;2m)</td>
<td>e</td>
<td>2&amp;6(5)</td>
<td>fd</td>
</tr>
<tr>
<td>f collapsed terraces</td>
<td>f</td>
<td>1&amp;1(2)</td>
<td>gd</td>
</tr>
<tr>
<td>D debris flow</td>
<td>g</td>
<td>2&amp;5</td>
<td>id</td>
</tr>
<tr>
<td>Ad accumulation of debris flow material</td>
<td>h</td>
<td>2&amp;6</td>
<td>jd</td>
</tr>
<tr>
<td>F flooding</td>
<td>i</td>
<td>2&amp;5</td>
<td>kl</td>
</tr>
<tr>
<td>Aw accumulation of water-transported material</td>
<td>j</td>
<td>2&amp;5</td>
<td>md</td>
</tr>
<tr>
<td>T major torrent activity</td>
<td>k</td>
<td>2&amp;5</td>
<td>md</td>
</tr>
<tr>
<td>t minor torrent activity</td>
<td>l</td>
<td>2&amp;6</td>
<td>pd</td>
</tr>
<tr>
<td>R rockfall source area</td>
<td>m</td>
<td>2&amp;5</td>
<td>rd</td>
</tr>
<tr>
<td>Ar accumulation of rockfall material</td>
<td>n</td>
<td>2&amp;5</td>
<td>rd</td>
</tr>
</tbody>
</table>
The complete polygon name

The polygon names are a composition of all levels of information available on the corresponding map. The first character, a number, represents the confirmed degree of hazard (see table 1), in case if the second character is also a number the unit area is suspected to a higher degree of hazard than indicated by the first character.

The following characters, letters, give information about the different types of hazard and their evidence. Four levels of evidence are possible:
- confirmed or inferred in less than 50% of the unit area, than there is only one letter which represents the type of hazard see second column of table 2.
- confirmed or inferred in more than 50% of the unit area, than a "d" follows the type identifier.
- suspected in less than 50% of the u.a., than a "s" follows the type identifier.
- suspected in more than 50% of the u.a., than "ds" follows the type identifier.

EXAMPLES:

<table>
<thead>
<tr>
<th>Polygon Name</th>
<th>Description</th>
</tr>
</thead>
</table>
| 21escbsf     | 2 -confirmed or inferred degree (see table 1)  
              | 1 -suspected higher degree (less than 50% of u.a.)  
              | es -deep landslide; suspected in less than 50% of unit area.  
              | c -surficial erosion, rills; confirmed or inferred in more than 50% of unit area.  
              | bs -shallow erosion by water ...; suspected in less than 50% of unit area.  
              | f -shallow landslide...; confirmed or inferred in less than 50% of unit area.  |
| 3aofb        | 3 -confirmed degree of hazard  
              | a -deep erosion by water ..; confirmed or inferred in less than 50% of unit area.  
              | o -major torrent activity..; confirmed or inferred in less than 50% of unit area.  
              | f -shallow landslide ..; confirmed or inferred in less than 50% of unit area.  
              | b -shallow erosion by water ..; confirmed or inferred in less than 50% of unit area.  |
Note:
- The first number occurs in every code.
- The second number does not occur necessarily.

The type identifiers are lined up closed together, if you keep in mind that the suffixes were "d" (dominant), "s" (suspected) and "ds" (dominant-suspected) recoding will be easier.

• Read the paper by Kienholz, H., Schneider, G., Bichsel, M., Grunder, M. and Mool, P.K. (1984) very carefully, as well as the text above, and the legend of the hazard map. Make sure that you understand the complicated legend and the way it was obtained.

• Display the map hazard. Open the table Hazard. Check the meaning of the columns. Open the domain htype, and compare it with the table on the previous page.

• Open the Pixel Information window, and add the map Hazard to it. Check the meaning of the various units. Compare the codes in the map with the tables above and the original paper map.

• Display the various types of hazard (hazardtype1 to hazardtype4) using display as attribute. Which types of hazard occupy most of the area?

• Compare the paper map Map No 4: Mountain hazards and Slope Instability with the digitized version.
EXERCISE 2

Preparing the data for the exercises

In this exercise you can familiarize yourself with the data set for the Kathmandu-Kakani study area. And you will prepare the raster maps with which you will do the analysis in the next exercises. Now all data is still in the vector format.

Create a Georeference Kakani, with the following characteristics:
- min X, Y: 621850, 71680
- max X, Y: 627780, 77200
- Pixel Size: 5 meters.
- Rasterize the following polygon maps, using the georeference Kakani: depo, erosion, ethnic, geology, hazard, landuse, man, mmriv, other, slide, sliden, slidenew, slow.

Elevation data

Create a Digital Elevation Model (DEM) for the Kakani area, by interpolating the contour lines.

Generate a slope map (in degrees) and a slope direction map.

Optional:
Create a hillshading map and make a three-dimensional view of the area.
Preparing a landslide map

As was explained in the previous section the original landslide map was digitized in a number of different files:

- mmriv.* Mass movements along creeks and rivers
- slide.* Mass movements on open slopes
- slow.* Slow mass movements
- other.* Other elements of erosion
- depo.* Deposition by mass movements
- man.* Man-made elements

In this section we will combine these files into one landslide map.

- Display the polygon map mmriv and check its contents with the Pixel Information window. Also display the polygon maps slide, slow, other, depo and man.

In order to make a combination of the different maps, and in order to make a useful analysis of the landslide map later, we have to change the legends of the files into a common legend. We do this by assigning a six-digit code to each of the legend units of the polygon maps.

Each digit of the code is related to a parameter. We will use the following parameters:

- **Type** 
  Landslide type (slide, flow or fall)
- **Subtype** 
  Movement mechanism (planar, slump, slow mass movement)
- **Activity** 
  Landslide activity (active, not active)
- **Depth** 
  Landslide depth (shallow, deep)
- **Material** 
  Landslide material (clastic material, weathered bedrock, fresh bedrock)
- **Scarp/body** 
  Erosional or accumulative part of the landslide

The number of each of these parameters is shown in the table below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/body</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1: Fall</td>
<td>s1: Planar</td>
<td>a1: Active</td>
<td>d1: Deep (&gt;5m)</td>
<td>m1: clastic material</td>
<td>b1: Accumulative part</td>
</tr>
<tr>
<td>t2: Flow</td>
<td>s2: Slow mass movement</td>
<td>a2: Not active</td>
<td>d2: Surficial (&lt;5m)</td>
<td>m2: debris flow material</td>
<td>b2: Erosive part</td>
</tr>
<tr>
<td>t3: Slide</td>
<td>s3: Slump (rotational)</td>
<td>a3: Unknown activity</td>
<td>du: Unknown depth</td>
<td>m3: fresh rock</td>
<td>bu: Unknown</td>
</tr>
<tr>
<td>tu: Unknown type</td>
<td>uk: Unknown subtype</td>
<td>au: Unknown activity</td>
<td></td>
<td>m4: weathered rock</td>
<td></td>
</tr>
<tr>
<td>mdepo: Deposition by mass movements</td>
<td>mde: Unknown depth</td>
<td>mma: Unknown material</td>
<td></td>
<td>mce: Unknown material</td>
<td></td>
</tr>
<tr>
<td>mman: Man-made elements</td>
<td>mman: Unknown accumulation</td>
<td>mman: Unknown erosio</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The names in the column above are preceded by a code, consisting of two characters. The first one indicates the type of information (t=type, s=subtype, a= activity, m= material, and b = scarp/body). The second character shows the class.

Now, each landslide can be described by a combination of these 6 codes.

Let's give some examples:
unit \texttt{scm} in the map \texttt{mmriv}: scarp of a slide or slump caused by stream erosion in clastic material
This unit will receive the code: \texttt{t3s3a1dum1b2}
type = t3 (slide), subtype = s3 (slump, assumed), activity = a1 (active, since it is not covered by vegetation),
depth = du (unknown), material = m1 (clastic material), scarp/body = b2 (scarp).

unit \texttt{swv} in the map \texttt{mmriv}: scarp of a slide or slump caused by stream erosion with vegetation
This unit will receive the code: \texttt{t3s3a2dumub2}
type = t3 (slide), subtype = s3 (slump, assumed), activity = a2 (not active, since it is covered by vegetation),
depth = du (unknown), material = mu (unknown), scarp/body = b2 (scarp).

unit \texttt{dbf} from the map \texttt{depo}: deposition of slides as boulders (fresh)
This unit will receive the code: \texttt{t3sua1dum1b1}
type = t3 (slide), subtype = su (unknown), activity = au (active, fresh boulders), depth = du (unknown),
material = m1 (clastic material, assumed), scarp/body = b1 (body)

Unfortunately not all these parameters are described for each of the legend units from the maps \texttt{mmriv},
\texttt{slide}, \texttt{slow}, \texttt{other}, \texttt{dep} and \texttt{man}. In some cases we can assume a certain parameter. In other
cases when we simply do not know it we will assign it as Unknown.

In an ideal case a landslide map should be prepared with the method explained in the theoretical part of this
course, using checklists during the photointerpretation and fieldwork, and by delineating each landslide as a
closed unit.

- Find out the six-digit code for the units from the maps \texttt{mmriv}, \texttt{slide}, \texttt{slow} and \texttt{depo}. We will not use the maps \texttt{other} and \texttt{man}, since they have features other than landslides.
  Fill in the values for type, subtype, activity, depth, material and scarp/body in the tables below. The codes for these units are given in the table on the previous page. Combine the codes in the column Key.

- After finishing the entry in the table compare the results with your colleagues.
Map: **slide**: Mass movements on open slopes

<table>
<thead>
<tr>
<th>code</th>
<th>name</th>
<th>Key</th>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>pbe</td>
<td>Planar slide in bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppv</td>
<td>Planar slide in clastic material partially with vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pnv</td>
<td>Planar slide in clastic material with vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rfc</td>
<td>Rockwall fresh and continuous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>riv</td>
<td>Rockwall interrupted by slopes covered with vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>scm</td>
<td>Scarp of a slide or slump in clastic material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sha</td>
<td>Scarp of a slide or slump in hardly weathered bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shi</td>
<td>Scarp of a slide or slump in highly weathered bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>swv</td>
<td>Scarp of a slide or slump with vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map: **depo**: Deposition by mass movements

<table>
<thead>
<tr>
<th>code</th>
<th>name</th>
<th>Key</th>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>dbf</td>
<td>Deposition of slides as boulders (fresh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dbo</td>
<td>Deposition of slides as boulders (partially overgrown)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dbw</td>
<td>Deposition of slides as boulders (partially weathered)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dcm</td>
<td>Deposition of slides as compact mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ddf</td>
<td>Deposition of slides as debris flow (fresh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ddo</td>
<td>Deposition of slides as debris flow (partially overgrown)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>od</td>
<td>Other deposition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map: **mmriv**: Scarp of a slide or slump caused by stream erosion

<table>
<thead>
<tr>
<th>code</th>
<th>name</th>
<th>Key</th>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>scm</td>
<td>Scarp in clastic material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sha</td>
<td>Scarp in hardly weathered bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shi</td>
<td>Scarp in highly weathered bedrock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>swv</td>
<td>Scarp with vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Map: **slow**: Slow mass movements

<table>
<thead>
<tr>
<th>code</th>
<th>name</th>
<th>Key</th>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>cd</td>
<td>Confirmed slow mass movement (deep &gt; 2 meter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cs</td>
<td>Confirmed slow mass movement (shallow &lt;2 meter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cu</td>
<td>Confirmed slow mass movement (undefined)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pd</td>
<td>Presumed slow mass movement (deep &gt; 2 meter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ps</td>
<td>Presumed slow mass movement (shallow &lt;2 meter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Create a domain **type** (class domain, in which you fill the names of the types, with their codes as indicated below).
  - t1: Fall, t2: Flow, t3: Slide, tu: Unknown type
- Create a domain **subtype** (class domain, in which you fill the names of the subtypes, with their codes as indicated below).
  - s1: Planar, s2: Slow mass movement, s3: Slump (rotational), uk: Unknown subtype
- Create a domain **depth** (class domain, in which you fill the names of the depth classes, with their codes as indicated below).
  - d1: Deep (>5m), d2: Surficial (<5m), du: Unknown depth
- Create a domain **material** (class domain, in which you fill the names of the material classes, with their codes as indicated below).
m1: clastic material, m2: debris flow material, m3: fresh rock, m4: weathered rock, mu: Unknown material

- Create a domain body (class domain, in which you fill the names of the scarp/body classes, with their codes as indicated below).
  
  b1: Accumulative part, b2: Erosive part, bu: Unknown accumulation/erosion

Now that the domains are made you can make attribute tables for the maps mmriv, slide, slow and depo, in which seven columns are made: key, type, subtype, activity, depth, material, and body.

- Create a table for the map mmriv. Add the column Key (with the string domain), and the columns Type, Subtype, Activity, Depth, Material and Scarp, which all have a domain with the same names.
- Fill in the columns as you have written them in the table on the previous page.
- Repeat the same procedure for the maps slide, slow and depo.

Now all four polygon maps with landslide information have an attribute table, which contains similar information. So now we can combine the maps. But before doing so we need to have a domain which contains all possible combinations of type, subtype etc.

- Create a class domain landsl. Open the table depo. Copy all the items from the column Key to the domain landsl. Tip: Select an item and press Ctrl+C (to copy it to the clipboard). Then activate the domain editor and press Insert. In the Insert box press Ctrl+V to paste the information.
- Copy all the codes in the column Key to the domain. The domain must contain unique names. So when you try to enter a name which already occurs, you will get an error message (Class name must by unique). Skip this one then and move to the next.
- When you have copied all the names in the column Key of table depo to the domain landsl, close the table depo and open the table mmriv. Repeat the procedure, also for the other maps (slide and slow).

The next step is to change the domain of the column key in each of the tables to the domain landsl.

- Open the table depo. Double-click on the title box of the column Key. Change the domain to landsl.
- Repeat the same procedure for the maps mmriv, slide and slow.

Now the polygon maps can be reclassified according to the information in the column Key of their attribute tables.
Make sure that the table depo is linked to the polygon map depo (you can make sure by changing the properties of the polygon map).

Create an attribute polygon map landsl1 by reclassifying the polygon map depo with the column Key.

Repeat the same procedure for the maps mmriv, slide and slow, and create the new polygon maps landsl2, landsl3 and landsl4.

The last thing to do is to combine the four maps (which now have the same domain) into a single map. Unfortunately we cannot do this with the vector maps, so we have to rasterize them first.

Rasterize the maps landsl1, landsl2, landsl3 and landsl4 using the georeference Kakani.

Combine the four raster maps into a single map landsl with a map calculation formula.

\[
\text{landsl} := \text{ifnotundef} (\text{landsl1}, \text{landsl1}, \text{ifnotundef} (\text{landsl2}, \text{landsl2}, \text{ifnotundef} (\text{landsl3}, \text{landsl3}, \text{landsl4})))
\]

Select the output domain landsl.

The final map landsl now has the combined information of the four maps. For each landslide it explains the type, subtype, activity, depth, material and scarp/body component. What should still be done is generate an attribute table for the map landsl, and generate the explanation columns. Since the name of each unit in the map landsl contains the combination of the codes of the six parameters, this is easy.

Create a table landsl (using the domain landsl).

You can obtain a column with the landslide types using the following equation in the table:

\[
\text{type} := \text{sub} (%K, 1, 2)
\]

Select the domain Type for the output column type.

With this formula you take a substring out of the domain names (%K). The substring starts at the first character, and is two characters long.

Note that the result of the calculation is a two character code, which is in fact the code of the domain type. So when you select the domain type, the resulting column will display the class names, instead of the codes. In the same way the columns subtype, etc. can be made.

You can obtain a column with the landslide subtypes using the following equation in the table:

\[
\text{subtype} := \text{sub} (%K, 3, 2)
\]

Select the domain subtype for the output column.

Create in the same way the columns: activity, depth, material, and body.
Link the table landsl to the raster map landsl.

Display the map landsl together with the drainage information and the roads, and use the Pixel Information Window to read the map and the table together. Also add the original polygon maps mnriv, slide, slow and depo to it. Check your results.

Now the landslide map is ready to be used in the data analysis.

The recent landslide map

Apart from the landslide map landsl, which is based on the paper map and show the landslide distribution in 1979, we also have prepared a map showing the present landslide distribution, called slidene. The maps shows the degree of activity (active, not active). The map is hypothetical, not based on real mapping, but only on a short fieldvisit.

Display the polygon map slidene

Rasterize the map, using georeference Kakani, call the result slidene
EXERCISE 3

Landslide distribution analysis

In this exercise you will learn how you can obtain information on the spatial distribution of different types of landslides, on the basis of a digital landslide hazard map. The method for preparing this map was explained earlier.

- Double-click the map Landsl. Click OK in the Display Options dialog box. The map is displayed.
- Move through the map and press the left mouse button for information on the various units. As you can see the area outside of the landslides reveals a ? when you press the left mouse button. These areas are called undefined. This means that no information is stored for the non-landslide areas. The landslides themselves all have a unique code.
- Move your mouse pointer to one of the landslides and double click on it. Now the information from the table connected to the map Landsl is displayed.

When you move the mouse pointer to one of the landslides, you will see that the attribute code is composed a twelve-character code for Type, Subtype, Activity, Depth, Material and Scarp.

- Each time you double click on a part of the map, the information from the table for that unit will be displayed. Try this out for several different units. Close the Edit Attribute window.
- Open the Pixel information window and drag-and-drop the map Landsl into it. Now if you move with the mouse pointer the information is shown without the need to double-click.
- To see what the table looks like, go to the main ILWIS window and open the table Landsl by double-clicking it. Have a look at the different columns. If you double-click the name of a column you get information on the column type.
- Close the table window.

The columns Type, Subtype, Activity, Depth, Material, Scarp are so-called class domain columns, in which each unit has a name. These names are defined in the domain files. See the table below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Subtype</th>
<th>Activity</th>
<th>Depth</th>
<th>Material</th>
<th>Scarp/Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1: Fall</td>
<td>s1: Planar</td>
<td>a1: Active</td>
<td>d1: Deep (&gt;5m)</td>
<td>m1: clastic material</td>
<td>b1: Accumulative part</td>
</tr>
<tr>
<td>t2: Flow</td>
<td>s2: Slow mass movement</td>
<td>a2: Not active</td>
<td>d2: Surficial (&lt;5m)</td>
<td>m2: debris flow material</td>
<td>b2: Erosive part</td>
</tr>
<tr>
<td>t3: Slide</td>
<td>s3: Slump (rotational)</td>
<td>a3: Unknown activity</td>
<td>du: Unknown depth</td>
<td>m3: fresh rock</td>
<td>bu: Unknown</td>
</tr>
<tr>
<td>tu: Unknown type</td>
<td>uk: Unknown subtype</td>
<td>au: Unknown activity</td>
<td></td>
<td>m4: weathered rock</td>
<td>accumulation/erosion</td>
</tr>
</tbody>
</table>
• Open the domain Activity by double-clicking it. As you can see each class has a name and a code. Each class domain also contains a representation, in which the colors for each class are defined.

• Open the representation Activity and have a look at the content. After that close the representation and the domain.

You can also display the map Landsl with an attribute from its table.

• Make the landslide map Landsl active, by clicking on a visible part of the map, or by selecting the upper left box of a window, and then switch to...

• Press the right mouse button while in the map, and select: 1.map Landsl. In the following Display Options dialog box click on Attribute and select the column Activity. Press OK. Now the map is redisplayed, with the colors from the representation Activity. If you click on a landslide you will see the activity information displayed.

• Also try this with some other columns (Type, Subtype, Activity, Depth, Material and Scarp).

• Close the map.

The data from the landslide maps, combined with the tabular data can be used to make landslide distribution maps. A landslide distribution map displays the occurrence of a specific group of landslides. These can be made by renumbering the landslide maps with a certain combination from the columns Type, Subtype, Activity, Depth, Material or Scarpbody in the accompanying table.

• Open the table Landsl. To calculate which landslides are active and deep, calculate the following formula:
  \[ \text{activedeep} : = (\text{activity} = \text{"active"}) \text{ and } (\text{depth} = \text{"deep"}) \]

• Accept the Bool domain for the output column. Close the table.

• Create an attribute map from the map Landsl and the column activedeep.

• Calculate a histogram of the result map. Now you know the area of the active and deep landslides.

In stead of calculating a new attribute map all the time, it is easier to calculate the histogram of the map landsl, and use this in the table landsl.

• Calculate the histogram of the map Landsl, and have a look at the resulting table. What is the total area occupied by landslides (Hint: use the aggregation option)?

• Open the table Landsl, and read in the column Area from the histogram.

• Calculate the total area within the study area, using another map (e.g. landuse or hazard).
• Calculate the percentage of the total area occupied by landslides.

It is also possible to know the area occupied by a certain type of landslides, or the percentage of the total area, by calculating within the table `Landsl` and using the column `Area`.

- Calculate the area for all combinations given in the table below. For each type of landslides, first calculate a column with 1 and 0 values, in which the 1 values are those that fulfill the requirement for a specific type. Then use the `AGGSUM` function (Aggregate sum), with the column `Area`, and the group column that you just made to know the area.

<table>
<thead>
<tr>
<th>Landslide type</th>
<th>Area in km²</th>
<th>Percentage of all landslides</th>
<th>Percentage of study area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in clastic material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in weathered rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in fresh rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surficial mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements with unknown depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scarps of landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body of landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Besides of the area occupied by different types of landslides, it is also possible to know the number of landslides. For this you need to run the operation `Area Numbering`, which will assign a unique code to each individual group of pixels with a certain name.

- Use the operation `Area Numbering` on the map `landsl`. Create an output map `Landslnr` with a domain `Landslnr`.
- Have a look at the resulting map and table.
- In the table `Landslnr`, use the `Join` operation to obtain the columns type, subtype, activity, depth, material, and scarpsbody from the table `landsl`.

- Calculate the number of landslides for the various types and fill in the table below. For each type of landslide, first calculate a column with 1 and 0 values, where the 1 values are the landslides of the specific type. Then use the `AGGCNT` function (Aggregate count) to know...
GISSIZ: GIS in Slope Instability Zonation

<table>
<thead>
<tr>
<th>Landslide type</th>
<th>Number of slides</th>
<th>Area</th>
<th>Average area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive planar slides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive slumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All active slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All inactive slow mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in elastic material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in weathered rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements in fresh rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surficial mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep mass movements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass movements with unknown depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scarps of landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body of landslides</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Besides of landslides we can also calculate the areas occupied by soil erosion. This can be done from the map erosion.

- Calculate all the areas occupied by soil erosion.
- Calculate all areas occupied by the different types of soil erosion.
EXERCISE 4

Landslide activity mapping

Now we will create a landslide activity map, by comparing the situation from 1979 with the recent situation. The landslide map from 1979 is called landsl and the one for the recent period slidnew. The analysis is done via a so-called two dimensional table, which makes a new value for the combination of the activities of two times:

<table>
<thead>
<tr>
<th>Activity in 1979: LANDSL</th>
<th>Recent Activity: SLIDENEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Active for long period</td>
</tr>
<tr>
<td>Not Active</td>
<td>Stabilized landslide</td>
</tr>
<tr>
<td>Not present</td>
<td>Active landslide cannot be detected anymore</td>
</tr>
<tr>
<td>Unknown</td>
<td>Previous activity unknown, now active</td>
</tr>
</tbody>
</table>

Table: Two-dimensional table used to analyze landslide activity.

Unfortunately we do not have two landslide maps of the Kakani area. We only have the map landsl which was made in 1979. In order to demonstrate you the procedure, we have invented a landslide map for the present situation, called slidew. Note that this map already shows the landslide activity (a1:active, a2: not active). So for the map slidew you only know the activity of landslides and not the type, subtype, depth, material and scarp information that you have for the map landsl.

For knowing the landslide activity we also need to know the areas which had no landslide in 1979, and now have one. In the map Landsl the areas without landslides are indicated with a ? (Undefined). This we need to change first.

- Create an attribute map Active by reclassifying the map landsl with the column Activity from the table landsl.
- Move your mouse pointer through the map, and consult the values. The areas outside the landslides are still undefined, because the map Landsl has undefined values for this areas. In the analysis you do not want to have undefined values, as you want to calculate the density of active landslides in each geological unit and each slope class.
- Copy the domain Activity to the new name: Active79, and add the name “not present”.
- To remove the undefined values from the map Active type the following formula in the command line:
  ```
  Active79 =iff(isundef(Active),"Not present", Active).
  ```
- Select the domain Active79 for the output map.
- Rasterize the map Slidenew, using the georeference Kakani.
- Copy the domain Slidenew to the new name: Active98, and add the name “not present”.
Also remove the undefined values from the map with the recent landslides (slidenew) with the formula:

\[
\text{Active98} = \text{iff(isundef(slidenew),"Not present", Slidenew)}
\]

Select the domain Active98 for the output map.

Create a two-dimensional table, called act7998 with Active79 as the primary domain and Active98 as the secondary domain. Press the create domain button and create the class domain Act7998, in which you enter the names as given in the table above.

Combine the maps Active79 and active98 with the two-dimensional table act7998, using the formula:

\[
\text{act7998} = \text{act8998[active79,active98]}
\]

Display the map act7998, and use the Pixel Information Window to look at the names in this map, and the two input maps (active79 and active98).

Calculate the areas of the changes (in hectares) and fill in the table below.

Draw conclusions on the changes in landslide activity.

---

**RECENT ACTIVITY: SLIDENEW**

<table>
<thead>
<tr>
<th>ACTIVITY IN 1979: LANDSL</th>
<th>Active</th>
<th>Not active</th>
<th>Not present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Area=</td>
<td>Area=</td>
<td>Area=</td>
</tr>
<tr>
<td>Not Active</td>
<td>Area=</td>
<td>Area=</td>
<td>Area=</td>
</tr>
<tr>
<td>Not present</td>
<td>Area=</td>
<td>Area=</td>
<td>Area=</td>
</tr>
<tr>
<td>Unknown</td>
<td>Area=</td>
<td>Area=</td>
<td>Area=</td>
</tr>
</tbody>
</table>

*Table: Two-dimensional table used to analyse landslide activity.*

A better landslide activity map should be obtained, by mapping the landslides as they are now in detail. Also the changes in landuse should be mapped in order to draw conclusion on the changes in landslide activity that we see in the area.

Create suitable colours in the representation Act7998. Create a map view, and add topographic information and a legend.
EXERCISE 5

Landslide density analysis

Landslide density analysis allows you to evaluate the density of landslide within particular landunits, which may be geomorphological units or geological units, for example. In this exercise you will calculate landslide densities in the units from the hazard map. What we want to do is to check whether the hazard map correctly displays the areas with active landslides as hazardous.

For the calculation we will use the map active79, which was made in the previous exercise. For the hazard map, we will simplify this map into a map only showing us the hazard classes.

- Make an attribute map hdegree by reclassifying the map hazard with the column hazarddegree.
- Cross the maps hdegree and active79. Save the cross-table as hdegact.

After crossing the maps, the next step is to calculate density values. You will do this only for active landslides.

Each of the calculation steps is indicated below.

- Make sure that the cross-table hdegact 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:
    \[
    Npixact=\text{iff(Active79}="\text{Active}",npx,0).
    \]
    You do this in order to calculate for each hazard class the number of pixels with only active landslides.

  - **Step 2**: Calculate the total number of pixels in each hazard class.
    Select from the table menu: Columns, Aggregation. Select the column: Npix. Select the function Sum. Select group by column hdegree. Deselect the box Output Table, and enter the output column Nptot. Press OK. Select a precision of 1.0.

  - **Step 3**: Calculate the number of pixels with active landslides in each hazard class.
    Again select from the table menu: Column, Aggregation. Select the column: Npixact. Select the function Sum, select Group by column hdegree. Deselect the box Output Table, and enter the output column Npact. Press OK. Select a precision of 1.0.

  - **Step 4**: Calculate the landslide density per slope class
    Type:
    \[
    \text{densact}=100* (Npact/Nptot).
    \]
    Select the output domain perc, with a precision of 0.1.
• Fill in the result in the table below.

<table>
<thead>
<tr>
<th>Hazard degree</th>
<th>Percentage Active landslides</th>
<th>Percentage Not active landslide</th>
<th>Percentage Landslides with unknown activity</th>
<th>Percentage landslides with no landslides</th>
</tr>
</thead>
<tbody>
<tr>
<td>High hazard for buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate to high hazard for humans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No hazards or instability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High hazard for humans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate torrential hazard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate to high hazard for buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mix of high hazard for humans and buildings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate hazard or instability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High torrential hazard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now you have calculated only the density (as a percentage cover for active landslides).

• Repeat the procedure for the not active landslides (output column densnotac), the landslides with unknown activity (densunknown), and the area without landslides (densno). Fill in the table above.

• Draw conclusion on how the hazard classification coincides with the actual landslide pattern.

After calculating the landslide densities in a table, you can renumber the original map hdegree with the landslide density values.

• Create a table hdegree for the domain hdegree. Join this table with the cross table hdegact. Get the values for the columns densact, densnotac, densunknown, and densno.

• Reclassify the map hdegree with the landslide density values from the column densact. The output map is called densact.

• Check the result with the Pixel Information Window. Also read the information from the map hazard. Draw conclusions.

What will be done finally is to make a landslide hazard map, in which in each hazard polygon the density of landslides determines the hazard degree.

• Reclassify the hazard map hdegree, but now purely on the basis of the information on the landslide densities within the various groups. Create a new map hazdens, which has three classes: high, medium and low hazard.

This map is a map made according to the landslide density method.

Additional exercise:
What you have done in the previous exercise was to calculate the density of landslide in each hazard class. What would be better is to do that for each individual hazard polygon.

- Design a method to calculate landslide density within each individual hazard polygon. Hint: use the operation Area Numbering.
- Check which hazard polygons are not correctly classified on the basis of the landslide density.
- Create a new landslide density map, in which you use landslide densities per polygon. Classify this map into three classes: high, medium and low hazard.
EXERCISE 6

Landslide isopleth mapping

A special way of calculating landslide densities is the use of a counting filter. Counting filters are used to count the number of pixels, within a certain search radius, around each central pixel. They can be used to count the number of point features, such as houses, wells or landslides. In this part of the exercise we will create a counting filter that will give us the number of landslide pixels within a radius of 10 pixels. The filter will look like this (see next page). Its form resembles a circle in which all the pixels within the circle (with a radius of 10 pixels) contain the value 1, and the rest the value 0. When we apply this filter on a binary map, showing the landslides, for each pixel the number of pixels with landslides within the 10 pixel radius is calculated.

Suppose you would like to know the spatial distribution of landslide density. A possibility is to define this density, for every pixel, as the number of pixels with landslides within a certain distance from that pixel. This is done by calculating with a more or less circular "filter" like the one shown above.

The size of the filter depends on the required distance and the map resolution (the pixel size).

The resulting map is a so-called landslide isopleth map.

You will first have to create the binary map with the landslides, using the information from the landslide map (landsl).

- Type the following formula on the command line:
  \[
  \text{slideyes} := \text{iff(isundef(landsl),0,1)}
  \]
- Press Enter. The Raster Map Definition dialog box is opened.
- Select the domain value, with a range from 0 to 1 and a Precision of 1. Click OK.
- Display the map slideyes and check if the map only contains 0 and 1 values. Close the map.
- Click the map slideyes with the right mouse button and select Image processing, and
the command Filter. The Filtering dialog box is opened.

- Click the Create button next to the list box Filter Name. The Create Filter dialog box is opened.
- Type the Filter Name: count, and for the description: Counting filter. Change the values for the number of rows and columns both to 21. Click OK. Now the Edit Filter dialog box is opened.
- Fill in the filter with 0 and 1 values, just as in the example on the previous page.
- Change the Gain to 1.0.

The gain is the value with which the result of the filter will be multiplied. When a linear filter is placed over the raster map, the filter will multiply all the values of the filter with the corresponding pixel values in the same position in the map. In our case this will result either in a 0 or in a 1. Then all the results of the individual filter cells are summed up and multiplied by the gain. For a counting filter the gain should be 1, since we want to know how many pixels there are with landslides, within a search radius of 10 pixels around every pixel. The resulting value will be stored in the central pixel, then the filter shifts one pixel further and does the same calculation.

Additional exercise

The map isopleth shows the number of landslides within a radius of 100 around every pixel. The pixel size that we use for our maps is 10 meters. If we want to know the landslide density, we should also know the area of the counting filter. The area of circle is given by the formula: \( \pi r^2 \) (where \( r \) = radius). So if \( r=100 \) meter, \( \pi r^2=31416 \text{ m}^2 \).

- Convert the map isopleth to a density map, showing the number of pixels with landslides per hectare.
- Classify the map into a number of classes using the Slicing operation.
- Convert the classified map to a vector map, showing different density contours.
EXERCISE 7

Creating a qualitative landslide hazard map.

The base map (Map No. 3) contains a classification of potentially damaged areas by mass movements. They apply a general rule, combining the geology, the slope angle, and the landuse.

- Study the legend of the Base Map carefully.
- Read from the paper by Kienholz, H., Schneider, G., Bichsel, M., Grunder, M. and Mool, P.K. (1984) the section dealing with the construction of the base map.
- Read from the paper by Caine and Mool (1982) the section on material properties.

From the map and the papers you can find out the rules that were applied in defining four classes of potential damage for areas with no actual damage, where damage is not significant and which have no forest cover. The degrees of instability were defined as following:

- Degree one.
  Theoretical unstable even when soil unsaturated, therefore unstable throughout the year. Mostly associated with phyllites and quartzites.

- Degree two.
  Theoretical unstable when soil is saturated. Only in areas with irrigable terraces. Unstable during wet season and periods of irrigation. Mostly underlain by gneisses.

- Degree three.
  Theoretical unstable when soil is saturated (irrigated terraces were excluded). Unstable during wetseason, mostly underlain by quartzites and phyllites.

- Degree four.
  Theoretical stable; mass movements not expected. Mostly on valley floors.
The landuse map has the following classes:

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>bl</td>
<td>Barren land</td>
</tr>
<tr>
<td>fo</td>
<td>Forest</td>
</tr>
<tr>
<td>gr</td>
<td>Grassland and pastures</td>
</tr>
<tr>
<td>ri</td>
<td>Riverbed</td>
</tr>
<tr>
<td>sl</td>
<td>Shrubland</td>
</tr>
<tr>
<td>td</td>
<td>Terrace (idle)</td>
</tr>
<tr>
<td>ti</td>
<td>Terrace (irrigable): Khet</td>
</tr>
<tr>
<td>tm</td>
<td>Terrace (mixed irrigable and non irrigable))</td>
</tr>
<tr>
<td>tn</td>
<td>Terrace (non irrigable): Bari</td>
</tr>
</tbody>
</table>

The geological map has 7 classes. If we insert the critical slope angles for drained and undrained conditions as given in Caine and Mool (1982), the table looks like this:

<table>
<thead>
<tr>
<th>Code</th>
<th>Name of Geology unit</th>
<th>Critical slope (drained conditions)</th>
<th>Critical slope (undrained conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ag</td>
<td>Augengneiss</td>
<td>44.2</td>
<td>24.4</td>
</tr>
<tr>
<td>bg</td>
<td>Biotitegneiss</td>
<td>41.5</td>
<td>20.8</td>
</tr>
<tr>
<td>g</td>
<td>Gneiss</td>
<td>41.5</td>
<td>20.8</td>
</tr>
<tr>
<td>qp</td>
<td>Quartz-phylite</td>
<td>32.8</td>
<td>18.5</td>
</tr>
<tr>
<td>q</td>
<td>Quartzite</td>
<td>32.8</td>
<td>18.5</td>
</tr>
<tr>
<td>tm</td>
<td>Tourmaline-Muscovite-Granite</td>
<td>42.8</td>
<td>21.8</td>
</tr>
<tr>
<td>tmp</td>
<td>Tourmaline-muscovite-Pegmatite</td>
<td>41.5</td>
<td>20.8</td>
</tr>
</tbody>
</table>

If we translate the rules stated in the base map the following decision rules can be applied (note that we use the codes of the landuse and geological units, instead of the names):
Each of these decision rules can be written as a formula. For example, decision rule 1 would be written as follows (for better understanding we have splitted up the formula into a number of parts, each on a different line)

```
map1=iff((
((geology="qp")or(geology="q"))
and
(slope>33)
and
((landuse="td")or(landuse="tm")or(landuse="tn"))
),1,0)  
```

So on one line the formula is:

```
map1=iff(((geology="qp")or(geology="q"))and(slope>33)and((landuse="td")or(landuse="tm")or(landuse="tn"))),1,0)
```

Now we can continue with the analysis. The decision rules nr 1 till 16 all have to be performed one after the other. Which means that the output of one rule serves as the input for another. This is done in the following way:

Decision rule 1:

```
map1=iff(((geology="qp")or(geology="q"))and(slope>33)and((landuse="td")or(landuse="tm")or(landuse="tn"))),1,0)
```
Decision rule 2:
map2=\text{iff}((\text{geology}=\text{"bg"}) \text{or} (\text{geology}=\text{"g"}) \text{or} (\text{geology}=\text{"tmp"}) \text{and} (\text{slope}>42) \text{and} ((\text{landuse}=\text{"td"}) \text{or} (\text{landuse}=\text{"tm"}) \text{or} (\text{landuse}=\text{"tn"})),1,\text{map1})

For the first decision rule, if the conditions are not met, the output is 0. For the second decision rule this is map1. This means if the conditions stated in the second decision rule are not met the values of map1 are not changed.

Write down the sixteen formulae for the sixteen decision rules given in the table on the previous page. Insert these formulae in your final report.

Execute the formula with the MapCalculation program. Make sure not to make typing errors. You can bring back the last formula by typing the up arrow several times.

When you have finished, make an appropriate colour representation for the final map potdam, and a legend.

Compare the result map with the Base Map on paper. Also compare it with the hazard map hazard.

map1=\text{iff}((\text{geology}=\text{"qp"}) \text{or} (\text{geology}=\text{"q"}) \text{and} (\text{slope}>33) \text{and} ((\text{landuse}=\text{"td"}) \text{or} (\text{landuse}=\text{"tm"}) \text{or} (\text{landuse}=\text{"tn"})),1,0)

map2=\text{iff}((\text{geology}=\text{"bg"}) \text{or} (\text{geology}=\text{"g"}) \text{or} (\text{geology}=\text{"tmp"}) \text{and} (\text{slope}>42) \text{and} ((\text{landuse}=\text{"td"}) \text{or} (\text{landuse}=\text{"tm"}) \text{or} (\text{landuse}=\text{"tn"})),1,\text{map1})

map3=\text{iff} ................................................

map4=\text{iff} ................................................

map5=\text{iff} ................................................

map6=\text{iff} ................................................

map7=\text{iff} ................................................

map8=\text{iff} ................................................

map9=\text{iff} ................................................

map10=\text{iff} ................................................

map11=\text{iff} ................................................

map12=\text{iff} ................................................

map13=\text{iff} ................................................

map14=\text{iff} ................................................

map15=\text{iff} ................................................

potdam=\text{iff} ................................................
**Additional exercise: Using a script in qualitative hazard mapping**

As you have found it is very cumbersome to write all these formulae in *MapCalculation*. One typing error, and you have to repeat the whole procedure.

To make this more easy, you can also put these formulae in a text file, and create a so-called script.

- Create a script called potdam, in which you write the sixteen formulas.
- Run the script.
EXERCISE 8

Statistical landslide hazard analysis

Summary
This exercise will show a method to make a hazard map based on quantitatively defined weight-values. Many different methods exist for the calculation of weight-values. The method used here is called the landslide index method. A weight-value for a parameter class, such as a certain lithological unit or a certain slope class, is defined as the natural logarithm of the landslide density in the class divided by the landslide density in the entire map.

Introduction
This method is based upon the following formula:

\[
\ln W_i = \ln \left( \frac{\text{Densclas}}{\text{Densmap}} \right) = \ln \left( \frac{\sum \text{Npix}(Si)}{\sum \text{Npix}(Ni)} \right)
\]

where,
- \( W_i \) = the weight given to a certain parameter class (e.g. a rock type, or a slope class).
- \( \text{Densclas} \) = the landslide density within the parameter class.
- \( \text{Densmap} \) = the landslide density within the entire map.
- \( \text{Npix}(S_i) \) = number of pixels, which contain landslides, in a certain parameter class.
- \( \text{Npix}(N_i) \) = total number of pixels 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.
Bivariate statistical analysis

Figure 9.1: Simplified flowchart for bivariate statistical analysis. In this exercise only 2 input maps are used.

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 9.1.

Preparing the data for the exercise

In this exercise the landslide hazard map is made by using only two parameter maps: Geology (geology) and Slope (slope map showing the slope in degrees). The landslides are stored in the map Landsl, which is linked to a table, containing detailed information for each landslide.

Before we can do the analysis, we should first classify the slope map in less classes.

- Open the map Slope and check its contents.
• Create a class, group domain slopecl, with classes of 10 degrees (so: 0-10 degrees, upper boundary 10 etc).
• Use the Slicing operation to classify the map Slope with the domain slopecl. The output map name should be slopecl.
• Open the map Geology and consult the information from the map and the accompanying table.
• Add the maps Geology, Slope, and slopecl to the pixel information window. When you move through the map you can simultaneously read the information from all three maps and their tables.
• Close the map windows and the pixel information window.

So far you have only been looking at the content of the maps. You will now start with the actual analysis.

Creating a landslide distribution map

Previously you created a map active79, which displayed the activities of the landslides in the study area. However, if you don’t have this map anymore, here is the method to regenerate it again.

• Create an attribute map Active by reclassifying the map landsl with the column Activity from the table landsl.
• Move your mouse pointer through the map, and consult the values. The areas outside the landslides are still undefined, because the map Landsl has undefined values for this areas. In the analysis you do not want to have undefined values, as you want to calculate the density of active landslides in each geological unit and each slope class.
• Copy the domain Activity to the new name: Active79, and add the name “not present”.
• To remove the undefined values from the map Active type the following formula in the command line:

```
Active79 =iff(isundef(Active),"Not present", Active)
```
• Select the domain Active79 for the output map.

Crossing the parameter maps with the landslide map

The landslide occurrence map, showing only the activity of the landslides (Active79) can be crossed with the parameter maps. In this case the two maps Slopecl and Geology are selected as examples. Of course in real applications many more parameter maps should be evaluated. First the map crossings between the occurrence map and the two parameter maps have to be carried out.

• Select from the main ILWIS menu the options: Operations, Raster operations, Cross.
• Select the map Slopecl as the first map, the map Active79 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 types from the map Active79.
Repeat the procedure for the crossing of the maps Geology and Activity. Name the output cross-table Actgeo.

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.

**Calculating landslide densities**

After crossing the maps, the next step is to calculate density values. You will do this only for active landslides.

Each of the calculation steps is indicated below.

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

  \[
  \text{Npixact}=\text{iff(Active79="Active",npix,0)}
  \]

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

- **Step 2**: Calculate the total number of pixels in each slope class.
  Select from the table menu: Columns, Aggregation.
  Select the column: Npix. Select the function Sum. Select group by column Slopecl. Deselect the box Output Table, and enter the output column Npsloptot. Press OK. Select a precision of 1.0.

- **Step 3**: Calculate the number of pixels with active landslides in each slope class.
  Again select from the table menu: Column, Aggregation.
  Select the column: Npixact. Select the function Sum. Select Group by column Slopecl. Deselect the box Output Table, and enter the output column Npslopeact. Press OK. Select a precision of 1.0.

- **Step 4**: Calculate the total number of pixels in the map.
  Again select from the table menu: Columns, Aggregation.
  Select the column: Npix. Select the function Sum. Deselect the box group by. Deselect the box Output table, and enter the output column Npmaptot. Press OK. Select a precision of 1.0.

- **Step 5**: The next step is to calculate the total number of pixels with landslides in the map.
  Again select from the table menu: Columns, Aggregation.
  Select the column: Npixact. Select the function Sum. Deselect the box group by. Deselect the box Output Table, and enter the output column Npmapact. Press OK. Select a step size of 1.0.

- **Step 6**: Calculate the landslide density per slope class
  Type:

  \[
  \text{Densclas=Npslopeact/Npsloptot.}
  \]

  Select a precision of 0.0001.

- **Step 7**: Calculate the landslide density for the entire map.
  Type:
GISSIZ: GIS in Slope Instability Zonation

Densmap=Npmapact/Npmaptot

Select a precision of 0.0001.

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

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

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 = 6887/437019 = 0.01576.

- Calculate the density of landslides in the entire map. Use this value in the formulas, when the word densmap is used.

Previously the calculation was done on the cross-table for the maps Slopecl and Active79. As you could see earlier on, this resulted in many redundant values, since you only want to calculate the densities and the weights for each slope class. In the resulting table 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.

- Create an attribute table Slopecl for the domain Slopecl. Open the table. 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 number of pixels in each slope class.

- Step 3: Calculate the number of pixels with active landslides in each slope class.

- Step 6: With both columns, you can calculate the landslide density in each slope class with the formula:
  Densclas:=Npslopact/Npsloptot
  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=0,0.00001,Densclas)

- The final weight can now be calculated with the formula:
Weight := \ln(\frac{D_{\text{clas}}}{\text{densmap}})

- In stead of the word densmap, fill in the actual value for the landslide density in the entire map, that you calculated before.
- Close the table.

Now you have calculated the weights for the map Slopecl.

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

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 Slopecl. Select attribute Weight. Select output raster map Wslope. Press OK.
- Display the resulting map Wslope. Stretch properly
- Use the same procedure the other parameter map Geology. The resulting map should be called: Wgeol.
- The weights for the two maps can be added with the formula:
  \[ \text{Weight} = \text{Wslope} + \text{Wgeol} \]
- Display the map Weight and use the pixel information window in order to read the information from the maps Slopecl, Wslope, Geology, Wgeol and Weight.

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.

- 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: final. 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.
Statistical hazard analysis with more maps

In the previous part you only used two input maps for the statistical analysis. Naturally, the occurrence of landslides is related to more factors. In this section you will generate the following parameter maps, and use them in a statistical analysis using a script.

<table>
<thead>
<tr>
<th>Map</th>
<th>Classes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>7</td>
<td>Geological units</td>
</tr>
<tr>
<td>Landuse</td>
<td>9</td>
<td>Landuse classes</td>
</tr>
<tr>
<td>Demclasc</td>
<td>6</td>
<td>Altitude classes (every 200 meters)</td>
</tr>
<tr>
<td>Slopeclasc</td>
<td>9</td>
<td>Slope classes (every 10 degrees)</td>
</tr>
<tr>
<td>Aspclasc</td>
<td>8</td>
<td>Slope aspect classes (every 45 degrees)</td>
</tr>
<tr>
<td>Rivdist</td>
<td>2</td>
<td>Distance classes from streams (&lt; 25 m or not)</td>
</tr>
<tr>
<td>Rivedist</td>
<td>2</td>
<td>Distance classes from streams with erosion (&lt; 25m)</td>
</tr>
<tr>
<td>Roaddist</td>
<td>2</td>
<td>Distance classes from the paved road (&lt; 25 m or not)</td>
</tr>
<tr>
<td>Pathdist</td>
<td>2</td>
<td>Distance classes from the footpaths (&lt; 25 m or not)</td>
</tr>
<tr>
<td>Rainclas</td>
<td>5</td>
<td>Classified annual rainfall (every 200 mm)</td>
</tr>
</tbody>
</table>

The drainage distance map

This map contains the drainage network, digitized from the base map.

- Display this map and look at the meaning of the codes.

For the statistical analysis, we need a map which displays the distance towards the nearest stream. We will make two distance maps:
- One that shows the distance towards all the streams, in classes of 25 meters.
- One that shows the distance towards the eroding streams, also with classes of 25 meters.

- Rasterize the segment map rivers using the georeference Kakani.
- Calculate a distance map from the map rivers. Call the result distriv.
- Reclassify the map distriv in two groups: less than 25 meters and more than 25 meters from the drainage. Call the result: rivdist.
- Repeat the procedure, but now calculate the distance calculation taking into account only the streams with erosion. Also classify the result. Call it rivedist.
The distance to roads map

This map contains the roads and paths in the study area. The only paved road is from Kathmandu to Trisuli, which is in fact the only traficable road in the area. The roads and paths are digitized from the base map. We will also need the distance from the road in classes of 10 meter.

- Display this map and look at the meaning of the codes.
- Create a classified distance map from the paved road (called roadist) the same way as for the rivers in the previous section.
- Create a classified distance map from the unpaved roads and footpaths (called pathdist) the same way as for the rivers in the previous section.

The rainfall map

As explained before we have a map with rainfall isohyets (lines with equal annual rainfall), derived from a sketch map. In order to use it in the statistical analysis you have to interpolate and classify the map.

- Interpolate the segments of the rainfall map and store the result into a rainfall map. Mask out the values outside of the study area. The final interpolated rainfall map should be called rain.
- Classify the map rain in units of 200 mm. each. Call the classified rainfall map rainclas.

The classified Dem

Another map that can be used in the statistical analysis is the digital elevation model (Dem). In order to use you need to classify it into classes of 200 meters.

- Classify the map dem in units of 200 meters. each. Call the classified rainfall map demclas.

The classified aspect map

Another map that can be used in the statistical analysis is the slope direction map (Aspect). In order to use you need to classify it into classes of 45 degrees meters.

- Classify the map dem in units of 45 degrees. each. Call the classified rainfall map aspelas.
Creating a script

- Create a script for the calculation of weight values (see the ILWIS Help and the User’s Guide for more information on scripts).
- Use the script to calculate the weights for each of the input maps. Write them in the tables on the next pages.
- Combine the weight maps into a final hazard map.
- Check the result by crossing it with the original landslide map.
- Compare the result with the one obtained using the qualitative hazard analysis.

Slope classes: map Slopecl

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 10 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10 - 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20 - 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30 - 40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>40 - 50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>50 - 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>60 - 70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>70 - 80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>80 - 90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Geological map: map Geology

<table>
<thead>
<tr>
<th>code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>ag</td>
<td>Augengneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bg</td>
<td>Biotitegneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Gneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>qp</td>
<td>Quartz-phyllite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>q</td>
<td>Quartzite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tmg</td>
<td>Tourmaline-Muscovite -Granite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tmp</td>
<td>Tourmaline-Muscovite-Pegmatite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Landuse map: map Landuse

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>bl</td>
<td>Barren land</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fo</td>
<td>Forest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gp</td>
<td>Grassland and pastures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ri</td>
<td>Riverbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sl</td>
<td>Shrubland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>td</td>
<td>Terrace (idle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ti</td>
<td>Terrace (irrigable): Khet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tm</td>
<td>Terrace (mixed irrigable and non irrigable))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gn</td>
<td>Terrace (non irrigable): Bari</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Classified altitude map: map Demclas

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1100-1300 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1300-1500 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1500-1700 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1700-1900 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1900-2100 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2100-2300 meters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Classified slope direction: aspclas

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-45 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>45-90 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>90-135 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>135-180 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>180-225 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>225-270 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>270-315 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>315-360 degrees</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Rivdist

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>less than 25 meters from all rivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>more than 25 meters from all rivers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Rivedist

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less than 25 meters from eroding rivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>More than 25 meters from eroding rivers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Roaddist

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less than 25 meters from paved roads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>More than 25 meters from paved roads</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Pathdist

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less than 25 meters from unpaved roads and paths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>More than 25 meters from unpaved roads and paths</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Rainclas

<table>
<thead>
<tr>
<th>Map number</th>
<th>Description</th>
<th>Landslide density</th>
<th>Weight values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EXERCISE 9

Deterministic landslide hazard zonation

Summary

In this exercise a simple slope stability model (the infinite slope model) is used to calculate safety factor maps for different conditions. The effect of groundwater depth and seismic acceleration is evaluated using input maps of these factors for different return periods of rainfall (related to the groundwater level) and earthquakes (related to the seismic acceleration). The model is generated as an ILWIS function. The different scenarios are calculated by changing the variables of the function. The model is applied to a data set of the Kakani area, in central Nepal.

Introduction

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. Many different models exist for the calculation of Safety Factors. Here we will use one of the simplest models, the so-called infinite slope model. This two dimensional model describes the slope stability of slopes with an infinitely large failure plane. It can be used in a GIS, as the calculation can be done on a pixel basis. The pixels in the parameter maps can be considered as homogeneous units. The effect of the neighboring pixels is not considered, and the model can be used to calculate the stability of each individual pixel, resulting in a hazard map of safety factors. The safety factor is calculated according the following formula (Brunsden and Prior, 1979):

\[ F = \frac{c' + (\gamma - m \gamma_w) z \cos^2 \beta \tan \phi'}{\gamma z \sin \beta \cos \beta} \]  

[6.1]

in which:

- \( c' \) = effective cohesion (Pa = N/m²).
- \( \gamma \) = unit weight of soil (N/m³).
- \( m \) = \( z_w/z \) (dimensionless).
- \( \gamma_w \) = unit weight of water (N/m³).
- \( z \) = depth of failure surface below the surface (m).
- \( z_w \) = height of watertable above failure surface (m).
- \( \beta \) = slope surface inclination (°).
- \( \phi' \) = effective angle of shearing resistance (°).

The infinite slope model can be used either on profiles as well as on pixels, as shown in figure 6.1. The entire analysis requires first the preparation of the data base. Since this is not available for the Kakani area, the process will be simplified.

The parts on groundwater modelling and the modelling of seismic acceleration are not shown here either. For more information see Van Westen (1993). In this exercise only part 3b1 will be demonstrated: the calculation of average safety factors for different scenarios. These average safety factor maps could be used in the creation of failure probability maps.
Which data are needed?

There are some variables in formula [6.1] which should be derived from maps, and others can be single values:

- $c'$ = effective cohesion (Pa= N/m$^2$).
  This is different for each geological unit. Therefore we will have to use a map, displaying this variable. The cohesion map can be made by renumbering the geological map.

- $\phi'$ = effective angle of shearing resistance (°).
  This is different for each geological unit. Therefore we will have to use a map, displaying this variable. The map can be made by renumbering the geological map with a table, containing the $c'$ values.

- $\gamma$ = unit weight of soil (N/m$^3$).
  This is also different for each geological unit. Therefore we will have to use a map, displaying this variable. The unit weight map can be made by renumbering the geological map with a table, containing the values.

- $\gamma_w$ = unit weight of water (N/m$^3$).
  This is a single value: 10 N/m$^2$

- $m$ = $z_w/w$ (dimensionless). To obtain the depth of the groundwater level we would need to do very detailed hydrological models, requiring a lot of fielddata. Since that is not possible we will simplify this by using the landuse map. The irrigated terraces will have a high groundwater table ($m=1$), and the other will have a lower groundwater table. This parameter can be obtained from the landuse map.

- $z_w$ = height of watertable above failure surface (m). Difficult to know.

- $z$ = depth of failure surface below the surface (m). This value we should specify for the entire area. For example 1 m or 2 m or 5 m.

- $\beta$ = slope surface inclination (°).
  This we have as a map: slope
Deterministic landslide hazard analysis

1. Preparation of geotechnical data base.
   - Slope map (slope)
   - Geological map (geology), with a table in which the values for $c'$, $\phi'$, and $\gamma$ are given for each geological unit.
   - Landuse map (landuse) which is used to determine the factor $m$.

2. Hydrological modeling:
   - Outside of GIS using existing models
   - Inside GIS through buffer analysis
   - Obtaining of groundwater levels with different return periods; establishment of scenarios

3. Modelling of seismic acceleration:
   - Using earthquake catalogues
   - Attenion curve
   - Geotechnical conditions
   - Obtaining of horizontal acceleration values with different return periods; establishment of scenarios

3a. Slope stability calculation outside GIS on profiles
   3a1. Selecting profiles and input data
   3a2. Run slope-stability calculations using different scenarios of groundwater and seismic acceleration
   3a3. Import results in GIS and convert to maps

3b. Slope stability calculation inside GIS on maps
   3b1. Calculating average safety factors for different scenarios of groundwater and seismic acceleration

To summarize, you will need the following data:
- Slope map (slope)
- Geological map (geology), with a table in which the values for $c'$, $\phi'$, and $\gamma$ are given for each geological unit.
- Landuse map (landuse) which is used to determine the factor $m$.

Display the map slope. This map contains slope angles in degrees.
The only unknown parameter yet is the depth of the water table. In formula 6.1 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 $\textit{Slope}$. In the calculation we need three parameters that are derived from the slope:

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

The ILWIS functions for sine and cosine only work with input values in radians, while our map $\textit{Slope}$ is in degrees. Therefore we need to convert to slope map from degrees to radians first. ILWIS has the function $\text{Degrad}$ for that:

\[
\text{Degrad}(\textit{Slope}) \text{ degrees to radians function: } \textit{slope} \times \frac{\pi}{360}
\]

- Type the following formula on the command line:
  \[
  \text{Slrad} := \text{degad}(\textit{Slope})
  \]
  Accept the default minimum, maximum and precision.
- Open the result map and compare the values of the map $\textit{Slrad}$ with those of the map $\textit{Slope}$. Calculate it with the ILWIS pocket line calculator or the Windows calculator for some pixels, using the formula given above.

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:
  \[
  \text{Si} := \text{sin}(\textit{Slrad})
  \]
  (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 $\textit{Si}$ with those of the map $\textit{Slrad}$. 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:
  \[
  \text{Co} := \text{cos}(\textit{Slrad})
  \]
  (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 $\textit{Co}$ with those of the map $\textit{Slrad}$. Check it for some pixels, using the formula given above.
- Type the following formula on the command line:
  \[
  \text{Co2} := \text{sq}(\textit{Co})
  \]
(with this formula you calculate the square of the cosine, using the ILWIS function \(\text{Sq}()\)).

Accept the default minimum, maximum and precision

- Check your results again.

You also need to make maps with values for \(c', \phi',\) and \(\gamma\), which are given for each geological unit

- Read the paper by Caine and Mool on landslides. Find out the values for \(c', \phi',\) and \(\gamma\) for each of the geological units. The unit weight values should be different for dry, wet and saturated conditions. For some geological units no data is given. Then use the data of similar geological units. Also make sure to have the data in the correct metrical units. Fill in the table below.

- Fill in the values in the table `geology`

- Create five maps: `coh` (cohesion), `tphi` (tangent of angle of internal friction), and `uwdry` (unit weight under dry conditions), `uwwet` (unit weight under wet conditions) and `uwsat` (unit weight under saturated conditions) by renumbering the map `geology` with the different columns from the table `geology`.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>(\tan \phi')</th>
<th>(c') (\text{Pa (N/m}^2)</th>
<th>(\gamma) dry (\text{N/m})</th>
<th>(\gamma) wet (\text{N/m})</th>
<th>(\gamma) sat (\text{N/m})</th>
</tr>
</thead>
<tbody>
<tr>
<td>ag</td>
<td>Augengneiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bg</td>
<td>Biotitegneiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Gneiss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>qp</td>
<td>Quartz-phyllite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>Quartzite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tmg</td>
<td>Tourmaline-Muscovite-Granite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tmp</td>
<td>Tourmaline-muscovite-Pegmatite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now all necessary parameters for the formula 6.1 are known, except for the parameter \(m\) related to the groundwater depth, and the depth to the failure plane (\(z\)).

**Creating a function for the infinite slope formula**

In the following sections you will use formula 6.1 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.

Besides many internal pre-programmed functions, ILWIS gives the user an opportunity to create new functions. Especially when you need to execute certain calculations which require a lot of typing work several times, user-defined functions may be time saving. A user-defined function is an expression which may contain any combination of operators, functions, maps and table columns.
Double-click New Function in the operations list. The Create function dialog box is opened.

Type for the Function Name: Fs

Type for the expression:

\[
\frac{(\text{Cohesion} + (\text{Gamma} - \text{M} \times \text{Gammaw}) \times \text{Z} \times \text{Co2} \times \text{Tanphi})}{(\text{Gamma} \times \text{Z} \times \text{Si} \times \text{Co})}
\]

Type the Description: Safety factor.

Click OK. The Edit Function dialog box is opened. Click OK.

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

Function fs(\text{Value Cohesion}, \text{Value Gamma}, \text{Value M}, \text{Value gammaw}, \text{Value Z}, \text{Value Co2}, \text{Value Tanphi}, \text{Value Si}, \text{Value Co}) : \text{Value}

Begin
Return \( \frac{(\text{Cohesion} + (\text{Gamma} - \text{M} \times \text{Gammaw}) \times \text{Z} \times \text{Co2} \times \text{Tanphi})}{(\text{Gamma} \times \text{Z} \times \text{Si} \times \text{Co})} \)
End;

As you can see the function contains the following variables (listed in the first line):
- \text{Value Cohesion}: the value for the effective cohesion.
- \text{Value gamma}: the value for the unit weight of soil.
- \text{Value m}: the value for the relation \( z_w/w \).
- \text{Value gammaw}: the value for the unit weight of water.
- \text{Value z}: the value for the depth of failure surface below the surface.
- \text{Value co2}: the value for the square of the cosine of the slope.
- \text{Value tanphi}: the value for the tangent of the effective angle of shearing resistance.
- \text{Value si}: the value for the sine of the slope.
- \text{Value co}: the value for the cosine of the slope.

However, a number of these variables are fixed. You will use them for all calculations: The fixed variables are: \text{Value Cohesion (raster map Coh)}, \text{Value Gammaw (10000 N/m}^2\text{)}, \text{Value Co2 (raster map Co2)}, \text{Value Tanphi (raster map tphi)}, \text{Value Si (raster map Si)}, and \text{Value Co (raster map Co)}.

So you can simplify the function considerably, so that it looks like:

Function fs(\text{Value Gamma}, \text{Value M}, \text{Value Z}) : \text{Value}

Begin
Return \( \frac{(\text{coh} + ((\text{Gamma} - \text{M} \times 10000) \times \text{Z} \times \text{Co2} \times \text{tphi}))}{(\text{Gamma} \times \text{Z} \times \text{Si} \times \text{Co})} \)
End;

As you can see there are only three variables: \text{Value Gamma}, \text{Value M}, and \text{Value Z}.
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 to the influence of an earthquake.

Dry condition

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

Remember the other parameter that were given on the previous page:

- $c'$ = Effective cohesion (Pa= N/m$^2$) = map coh
- $\gamma$ = Unit weight of soil (N/m$^3$) = map uwdry
- $\gamma_w$ = Unit weight of water (N/m$^3$) = 10000 N/m$^3$
- $z$ = Depth of failure surface below the surface (m) = unknown
- $m$ = Relation $z_w/z$ (dimensionless) = 0
- $\tan(\phi')$ = Tangent of the effective angle of shearing resistance = map tphi
- $\sin(\beta)$ = Sine of slope angle = map Si
- $\cos(\beta)$ = Cosine of slope angle = map Co
- $\cos^2(\beta)$ = Square of the cosine of slope angle = map Co2

Now you can start with the actual calculation of the average safety factor map representing the situation under dry conditions.

Since we don’t have data on depth of failure planes, we will work with a few predefined depths: 2 meter and 5 meters.

First let us calculate for a failure depth of 2 meter.

The three variables for the function $fs$ are $uwdry$ (Value Gamma), 0 (Value M), and 2 (value z),

```
• Type the following formula on the command line:
  Fdry2m:=fs(uwdry,0,2)
  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 Fdry2m with those of the input maps. Calculate the safety factor manually for some pixels with the Pocket line calculator or the Windows calculator, using formula 6.1.
```

The map $F_{dry2m}$ 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 $F_{dry2m}$ 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 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>

- Use the Slicing operation to classify the map Fdry2m with the domain Stabil into the map Fdry2mc.
- Calculate a histogram of the map Fdry2mc and write down the percentages of the three classes in the table below with the column name Dry2m. Later we will calculate the values for other situations.

The percentage of the pixels classified as unstable gives you an indication of the error, since the occurrence of unstable pixels under fully dry conditions is not possible.

<table>
<thead>
<tr>
<th></th>
<th>dry2m</th>
<th>dry5m</th>
<th>wet2m</th>
<th>wet5m</th>
<th>sat2m</th>
<th>sat5m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To calculate the stability under dry conditions for a failure depth of 5 meters:

- Type the following formula on the command line:
  \[ F_{dry5m} := fs(uwdry, 0, 5) \]
- Open the result map and compare the values of the map Fdry5m with the maps Fdry2m and the input map. Calculate the safety factor manually for some pixels with the ILWIS pocket line calculator or the Windows calculator for some pixels, using the formula given above.
- Use the Slicing operation (under image procession) to classify the map Fdry5m with the domain Stabil into the map Fdry5mc.
- Calculate a histogram of the map Fdry5mc and write down the percentages of the three classes in the table with the column name dry5m. Compare them with the column Dry2m. Later we will calculate the values for other situations.

**Completely saturated condition**

The next scenario that you will evaluate is a condition in which the slopes are completely saturated. This is also not a very realistic situation, but it will give us the most pessimistic estimation of slope stability, with only one triggering factor involved (rainfall leading to high watertables).

When we have a saturated soil, the \( m \) factor from formula 6.1 is equal to 1. This means that the watertable is at the surface. There is also another factor which is different for saturated conditions \( \gamma \):

\[
\begin{align*}
  \gamma &= \text{Unit weight of soil (N/m}^3) = \text{map uwsat} \\
  c' &= \text{Effective cohesion (Pa= N/m}^2) = \text{map Coh}
\end{align*}
\]
\[ \gamma_w = \text{Unit weight of water (N/m}^3) = 10000 \text{ N/m}^3 \]
\[ z = \text{Depth of failure surface below the surface (m)} = 2 \text{ or 5 meters} \]
\[ m = \text{Relation } z_w/z \text{ (dimensionless)} = 1 \]
\[ \tan(\phi') = \text{Tangent of the effective angle of shearing resistance} = \text{map } tphi \]
\[ \sin(\beta) = \text{Sine of slope angle} = \text{map } Si \]
\[ \cos(\beta) = \text{Cosine of slope angle} = \text{map } Co \]
\[ \cos^2(\beta) = \text{Square of the cosine of slope angle} = \text{map } Co2 \]

The three variables for the function \( fs \) if we take a depth of 2 meters are \( uwsat \text{ (value } \gamma_w \text{), } 1 \text{ (value } m \text{), and } 2 \text{ (value } z \text{).} \)

- Type the following formula on the command line:
  \[ F_{sat2m} = fs(uwsat,1,2) \]
- 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 \( F_{sat2m} \) with the maps \( F_{dry2m} \) and \( F_{dry5m} \) and the input maps. Calculate the safety factor manually for some pixels with the ILWIS pocket line calculator or the Windows calculator for some pixels, using the formula given above.
- Use the Slicing operation (under image procession) to classify the map \( F_{sat2m} \) with the domain \( Stabil \) into the map \( F_{sat2mc} \).
- Calculate a histogram of the map \( F_{sat2mc} \) and write down the percentages of the three classes in the table with the column name \( Sat2m \). Compare them with the other columns \( Dry \). Later we will calculate the values for other situations.
- Also calculate the same for saturated conditions and a failure depth of 5 meters.

**Other groundwater scenarios**

Using these formulae and the input files created in the previous exercises, a number of scenarios can be calculated, if you have information on groundwater depths. As these are not available for the area, the only thing we can do is to assume some intermediate steps, with different groundwater depths and \( m \) values. Here we will calculate only the effect of \( m=0.5 \), which means that the groundwater is at half the failure depth.

We will also calculate it for two conditions: 2 meter and 5 meter failure depth.

- To calculate the safety factor map for 2 meters, type the following formula on the command line:
  \[ F_{wet2m} = fs(uwwet,0.5,2) \]
  with this formula you calculate the safety factor for a situation where \( m=0.5 \) and the failure depth is 2 meters. Not that we now use the unit weight information for wet conditions.
- Use the Slicing operation to classify the map \( F_{wet2m} \) with the domain \( Stabil \) into the map \( F_{wet2mc} \).
- Calculate a histogram of the map \( F_{wet2mc} \) and write down the
percentages of the three classes in the. Compare them with the other columns.

• Then calculate safety factor maps for the other failure depth.

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

• Create a table from the domain Stabil.
• Go to Columns, Join and select Table histogram of Fdry2mc; use the column Npixpct. The output column is Dry. Accept the default values.
• Also join the histogram files of the maps Fdry5mc, Fwet2mc, Fwet5mc, Fsat2mc and Fsat5mc.
• Select Options, Show Graph and display each of these columns as y against the Stabil value as bar graphs in different colors.
• Draw conclusions on the effect of the groundwater and the failure depth on the stability of the soils in the area.