Training Package on National Scale Multi-
Hazard Risk Assessment

Exercise Book

National Scale Multi-Hazard Risk Assessment, with an example of Georgia

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I: http://www.itc.nl/about_itc/resumes/westen.aspx
http://www.itc.nl/about_itc/resumes/damen.aspx

Note about the PPRD-EAST project

This manual is produced in the framework of the PPRD-EAST project, which is the EU-funded Programme for the Prevention, Preparedness and Response to Man-made and Natural Disasters in the ENPI East Region (PPRD East)

The PPRD East programme focuses on natural and man-made disasters with special emphasis on the ones identified as priorities in the region. Complex emergencies are not part of this programme. The most common disasters on which the programme will focus are notably:
- Seismic risks
- Hydro-geological events (such as floods/flash floods/droughts)
- Forest and ground fires
- Urban/industrial disasters (e.g. explosions, fires, chemical accidents or toxic gas leakage, obsolete pesticides), road accidents, etc.
- Disasters caused by extreme meteorological conditions (which may or not be related to climate change)

The programme tackles these risks at the level of preparation, preparedness and mitigation and at the level of response management. It includes four sets of actions, which will result in:
- an improved knowledge base concerning the current state of play,
- strengthened prevention, preparedness capacities and response (from the administrative, operational and legislative points of view), and
- wider information and awareness. These actions must also work towards the greater goal of a progressively stronger association of the Partner Countries with the European Mechanism of Civil Protection.

The overall objectives of the Programme PPRD East:
- to contribute to the development of the Partner Countries' civil protection capacities for disaster prevention, preparedness and response
- to bring the Partner Countries progressively closer to the EU Civil Protection Mechanism and improve cooperation among themselves.

Note about contributors

The following persons and organisations contributed to the work described in this training material

Lead partner responsible for the training manual:
- Faculty ITC, University of Twente, The Netherlands: Cees. van Westen, Dinand Alkema, Wim Feringa, Nanette Kingma and Michiel Damen

Persons and organizations that have contributed tot he generation of the national scale mulit-hazard risk assessment of Georgia
- Faculty ITC, University of Twente, The Netherlands (Cees. van Westen, Menno Straatsma, Ulan Turdukulov, Wim Feringa)
- GeoMapa (Koert Sijmons)
- CENN (Nino Kheladze, Kakha Bakhtadze, Levan Natsvlishvili and Nodar Tkhelidze)
- National Environmental Agency of the Ministry of the Environment Protection of Georgia (George Gaprindashvili, Irakli Megrelidze, Gigi Geladze)
- Emergency Management Department of the Ministry of Internal Affairs of Georgia (Vakhtang Gloveli)
- Ilia State University (Lasha Sukhishvili, Mikheil Elashvili)
- Tamar Tsamalashvili
- Irvin T. Feliciano, Santiago

CONTENTS

1 INTRODUCTION AND OBJECTIVES

1.1 OBJECTIVES

This case study deal with the procedures to collect, analyse and evaluate spatial information for multi-hazard and risk assessment at a national scale, with a case study of the country of Georgia. The chapters of this exercise manual will guide participants through the main components of risk assessment, such as the collection of historic disaster databases, the generation of elements-at-risk maps, single hazard assessment, multi-hazard assessment, vulnerability assessment, exposure analysis and risk analysis.
The target group for this training manual on GIS for risk assessment consists of University students, researchers and practioners on hazard and risk assessment. The training materials can be used by individuals as personal training, or can be used in training courses. In that case a reference to the project and to the partner that generated the training package is required.

1.2 OPEN SOURCE SOFTWARE: ILWIS

In the development of the training materials one of the driving aspects was that the exercises, the data and the software should be freely available for all interested to learn about the dissemination results of the PPRD-EAST project. Therefore it was decided to base all the exercises on Open Source software. We decided to use the ILWIS software, as this is easy to learn, comprehensive and has an extensive set of tutorial material.

ILWIS is an acronym for the **Integrated Land and Water Information System**. It is a *Geographic Information System* (*GIS*) with *Image Processing* capabilities. ILWIS has been developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands up to release 3.3 in 2005. ILWIS comprises a complete package of image processing, spatial analysis and digital mapping. It is easy to learn and use; it has full on-line help, extensive tutorials for direct use in courses and 25 case studies of various disciplines (See www.itc.nl)
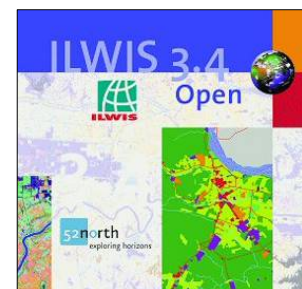
Since July 2007, ILWIS software is freely available ('as-is' and free of charge) as open source software (binaries and source code) under the 52°North initiative (GPL license). This software version is called ILWIS Open. ILWIS software can be downloaded for free from **52 North:** http://52north.org/

As a GIS package, ILWIS allows you to input, manage, analyze and present geo-graphical data. From the data you can generate information on the spatial and temporal patterns and processes on the earth surface.

1.3 INSTALLING AND STARTING THE ILWIS SOFTWARE

Before you can start with the exercises you will have to download the software. We have decided to use the version 3.4 which is not the most recent version of the ILWIS software, but one which is well proven stable and has all the functionalities required for carrying out the exercises. The latest versions of ILWIS have some major changes in terms of the visualisation and the exercise texts are not adapted to that.

To install the software, please follow these steps:

- Download the file: **Ilwis_3.4_Open.zip** from the 52 North web ftp site (if it is not yet installed) or from the dataset provided to you.

- Unzip the file in a directory on the D (or C) drive. Not on the desktop.

- Run **ILWIS34Ssetup.exe** to install the software.

- The zip file also contains a directory **Users Guide** This folder contains the complete ILWIS 3.0 User's Guide (in .pdf format). with a file describing what changed in ILWIS 3.1. ILWIS 3.4 has new functionality, but the same file describes how to use the ILWIS 3.0 User's Guide with ILWIS 3.4. Data for these basic tutorials can be downloaded from http://www.itc.nl/ilwis/documentation/version3.asp

In the exercises we are using this font and this colour to indicate the actual software instructions. General information and explanation is written in Black (Times Roman)

- Before you use ILWIS first unzip the data of the first exercise (**Exercise_Introduction**) into a directory **\exercise01** on the C or D drive.

- To start ILWIS, double-click mouse the **ILWIS** icon on the desktop. After the opening screen you see the ILWIS Main window (see figure below). From this window you can manage your data and start all operations

- Use the ILWIS Navigator (Navigation pane) to go to the sub- folder of the exercise. The Navigator lists all drives and directories (i.e. folders) in a tree structure.
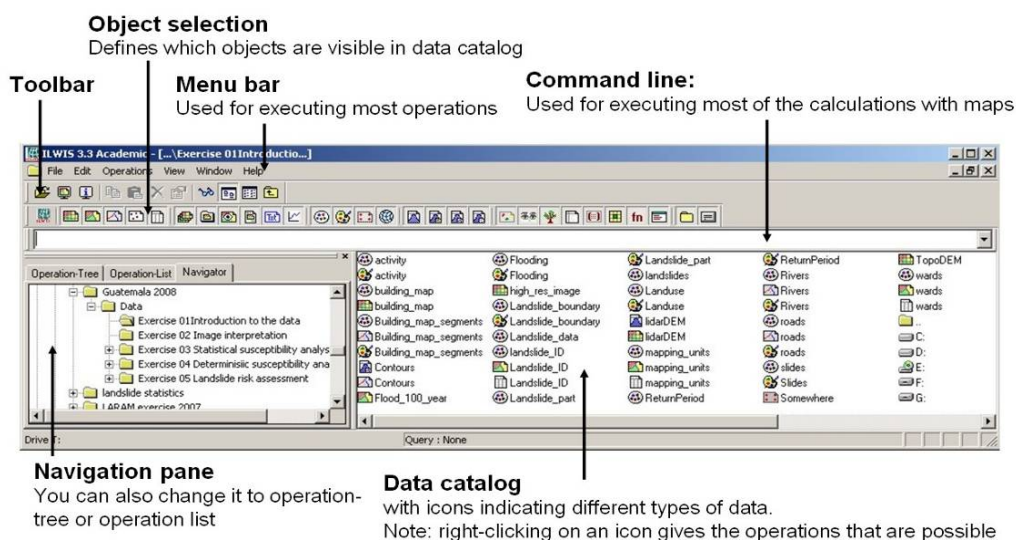
The ILWIS Window contains a number of features:

- **Data catalog**: displays the icons and names of the objects inside the selected directory.
- **Standard Toolbar**: provides shortcuts for some regularly used menu commands

  The Standard toolbar has the following buttons:

📂	New Catalog	🖳	Properties
🖥	Open Map	∿	Customize Catalog
ⓘ	Open Pixel Information	🔲	List
📋	Copy	▦	Details
📋	Paste	🔲	cd..
✕	Delete		
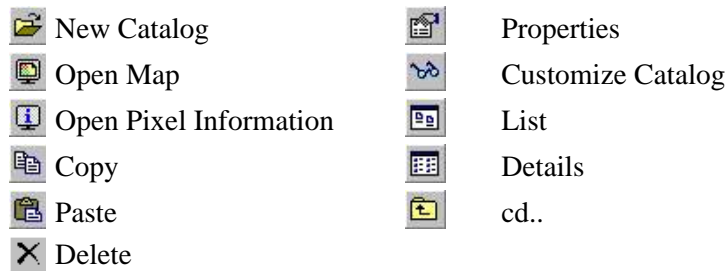
- **Navigation pane**: allows for fast navigation, and can also be changed to display all operations
- **Menu bar**: this is the main starting point for doing most of the operations in ILWIS. Check especially the options under Operations. The ILWIS Main window has six menus: **File, Edit, Operations, View, Window** and **Help**.

- **Command line:** this is a central facility in ILWIS. Here you type calculation statements (called **MapCalc**) which allows you to do a lot of analysis steps with raster maps. If you do an operation, the related ILWIS command is also displayed.

- **Object selection:** this allows you to select which objects are displayed in the data catalog

- **Getting HELP :** allows you to obtain information from any point within the program. The Help menu differs per window.

ILWIS uses different types of objects.

- *Data objects.* Raster maps, polygon maps, segment maps, point maps, tables and columns are called data objects. They contain the actual data.

- **Service objects**. Service objects are used by data objects; they contain accessories that data objects need besides the data itself. Domains, representations, coordinate systems and georeferences are called service objects.

- **Container objects.** Container objects are collections of data objects and/or annotation: map lists, object collections, map views, layouts and annotation text.

- **Special objects.** Special objects are histograms, sample sets, two-dimensional tables, matrices, filters, user-defined functions and scripts.

A vector map needs a coordinate system, a domain and a representation. These service objects are also needed for raster maps, together with another type of service object: a georeference. In this chapter we will focus our view on data and service objects.
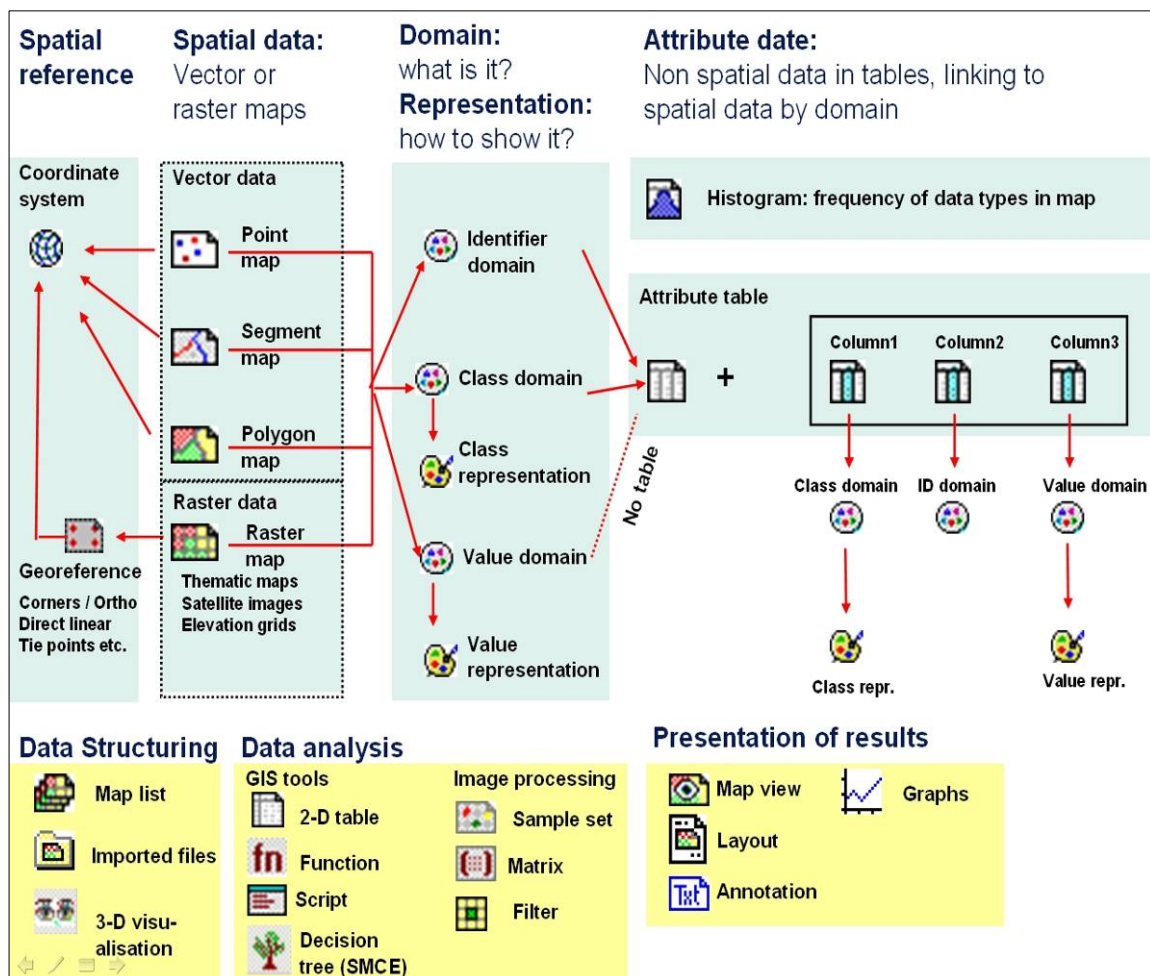
1.4   ABOUT THE GEORGIA HAZARD AND RISK MAPPING PROJECT

In these exercises we will generate a qualitative risk map for the country of Georgia, located between Turkey, Armenia, Azerbeidjan, Russia and the Black Sea in the Caucasus mountain chain. The South Caucasus is a region which is quite vulnerable to natural disasters by the complexity of its geological structure, diversity of geomorphologic, hydro-climatic and geo-ecological conditions. In all three nations of the South Caucasus (Azerbaijan, Armenia and Georgia) earthquakes, landslides, avalanches, floods and other natural calamities occur frequently, which cause human tolls and economic losses. According to various data, the economic losses caused by elemental natural processes in the above noted countries during recent 2 decades exceeded 16 billion dollars.[1]

1.5   RISK ATLAS

The data for Georgia was produced in the framework of the project "Institutional Building for Natural Disaster Risk Reduction (DRR) in Georgia" which was implemented by the Caucasus Environmental NGO Network (CENN) and the Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, the Netherlands from 2009 to 2012. The project was financially supported by the Social Transformation Programme for Central and Eastern Europe (MATRA) of the Netherlands Ministry of Foreign Affairs. The project was directed towards the provision of capacity building of governmental institutions in Disaster Risk

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[1] *Central Asia and Caucasus Disaster Risk Management Initiative* (CAC DRIM) *Risk assessment for Central Asia and Caucasus*, The World Bank, 2009, page 63, http://www.unisdr.org/files/11641_CentralAsiaCaucasusDRManagementInit.pdf

Management (DRM) and Disaster Risk Reduction (DRR) and an introduction to the modern spatial approaches and technologies in territorial planning in Georgia.

As one of the outcomes of the project a risk atlas has been produced. The atlas is dealing with 10 types of hazards (earthquakes, flooding, landslides, mudflows, rockfall, snow avalanches, drought, wildfire, windstorm, hailstorm), and 8 types of elements-at-risk (population, buildings, GDP, roads, pipelines, forest, crops and protected areas). We generated databases of past hazard events, exposure maps, created physical, social, economic and environmental vulnerability maps, and risk maps for all combinations of hazard and assets. Three different levels of administrative units were used for aggregation of the exposure and risk results: regional, districts and community. We produced a paper atlas that gives a concise overview of the base data, and project output.
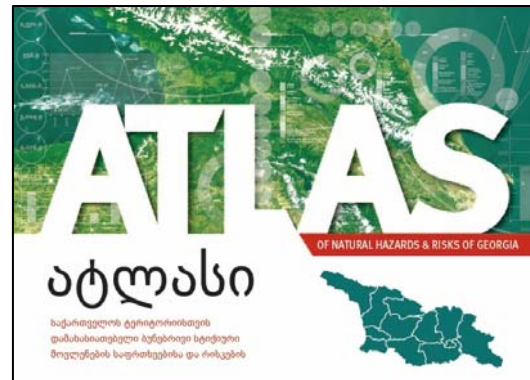
Task:
- Consult the risk atlas in pdf form from the following website: http://drm.cenn.org/index.php/en/background-information/paper-atlas
- You can also consult the atlas as an e-book on the following site: http://issuu.com/grammallc/docs/atlas_of_risk?e=5243266/2932778
- In case also paper version of the atlas are available, you can also use these.
- Spend some time to go through the atlas and see the various components, maps and data used for the generation of the national scale multi-hazard risk atlas.

1.6   WEB-GIS

In the field of disaster management internet based technologies are already widely used for the communication of risk information. Within the project a web-based risk atlas was developed as a risk communication tool. It allows the user to combine different types of information, and display this information in a variety of ways, for example: hazard maps of individual hazard types; information on elements at risk; exposure maps; vulnerability maps and maps of individual, specific risk types. The web-GIS contains the following components:

- Reporting of new hazard events by the public through a simple interface.
- Querying of past event database.
- Querying of hazard, exposure and risk maps, and obtain statistical information per administrative unit.
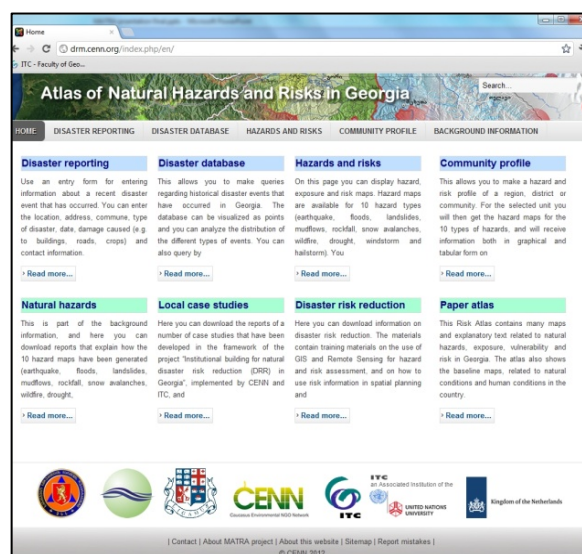
- Generate a full hazard, exposure and risk report for each administrative unit of the country, in three levels (regions, districts, and communities).
- Background information on geo-information for disaster risk management, and local case studies.

Tasks:
- Have a look at the web-based risk atlas at: http://drm.cenn.org/index.php/en/
- Try to report a new hazard event using the interface to see how this is done
- Select a certain administrative unit (region, district or community) and evaluate the types of hazards.
- Also analyse the exposure and eventually the risk for that specific unit.
- Generate a full hazard, exposure and risk report for the administrative unit selected (regions, districts, and communities).

1.7 METHODOLOGY USED FOR MULTI-HAZARD RISK ASSESSMENT IN GEORGIA

It is well known that risk assessment is a process that determines the extent and nature of risk by combining the technical characteristics of hazards, people's vulnerability conditions and their exposure (UN/ISDR, 2004b). Thus, Disaster Risk can be conceptually represented as:

Disaster risk = Hazard * Vulnerability * Amount of elements at risk

There are three important components in risk analysis: 1) hazards; 2) vulnerability; and 3) elements-at-risk. They are characterized by both spatial and non-spatial attributes. Hazards are characterized by their temporal probability and intensity, derived from frequency-magnitude analysis. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon within a specified period of time (a reference period). In the analysis we have taken into account 10 diferent hazard types: earthquakes, floods, landslides, mudflows, rockfall, snow avalanches, wildfire, drought, windstorm and hailstorm. For each of these hazard types a susceptibility maps was generated, classified into three classes (high, moderate and low). The historical information on past events was used to estimate the number of events that are likely to happen in a reference period of 50 years, and the size of individual events. The spatial probability was then calculated by dividing the area of the expected events by the total area of each hazard class. The historical data on past hazardous events and the hazard maps will be presented in chapter 3.

Vulnerability and exposure was estimated for the following types of elements at risk: buildings, population, GDP, roads, forests, crops and natural parks. These factors will be presented in chapter 2 (baseline data). For each combination of hazard type and element at risk the overlapping areas were calculated with a GIS, resulting in the exposure information, which will be presented in Chapter 4. Social, physical, environmental and economic vulnerability was expressed using a qualitative spatial mult-criteria evaluation technique, presented in the next section. Vulnerability values were estimated for each combination of a hazard class (high, moderate and low) for each of the 10 hazard types, and the elements at risk, and presented in a matrix. These were then used in the estimation of the final risk maps.

The figure below shows the overall risk assessment methodology represented by input maps that were used for the analysis.
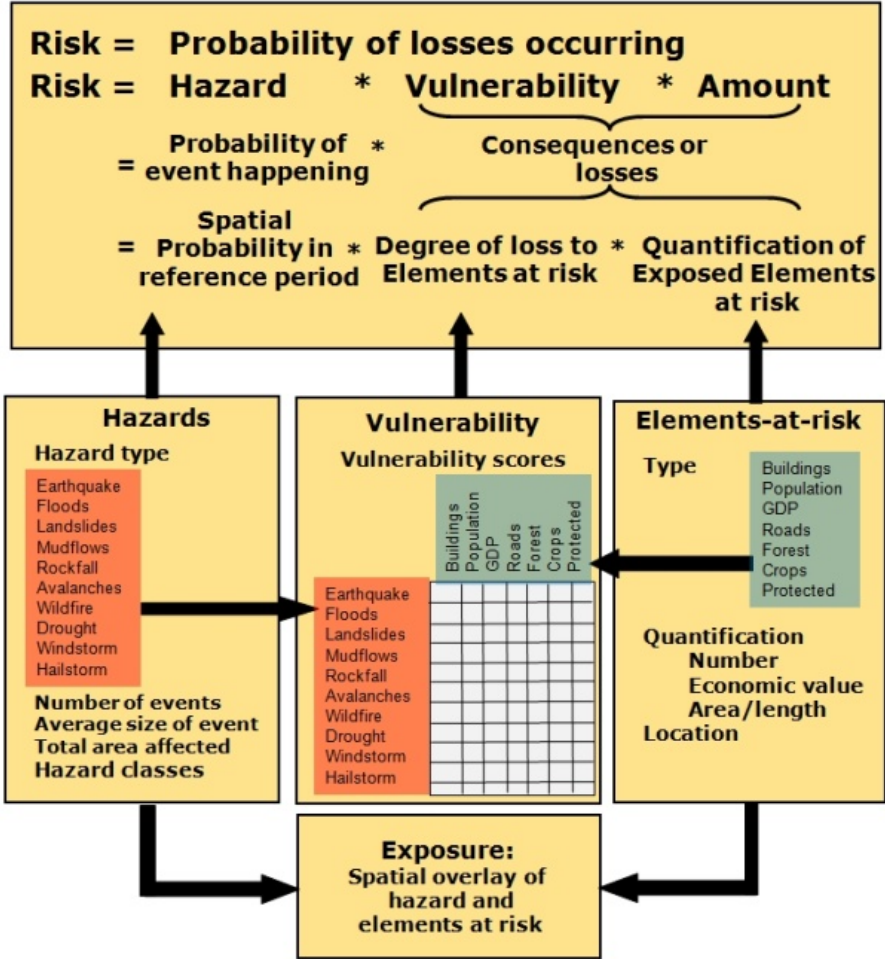
Figure: schematic representation of the procedure followed.

2 DOWNLOADING AND PROCESSING INPUT DATA FOR NATIONAL SCALE MULTI-HAZARD RISK ASSESSMENT

Expected time: 7 – 8 hours (for all exercises) – Selection possible
Data: To be downloaded and/or already provided by the lecturer
Objectives - After this exercise you will be able to:

- Download from the internet selected data for national scale multi-hazard risk assessment
- Import the downloaded data into the ILWIS software
- Perform basic processing steps in ILWIS
- Critically analyze the quality of the data

2.1 INTRODUCTION

Various data to be used for national scale multi-hazard risk assessment can be downloaded at no costs from selected internet portals. In this exercises we will explain how to do this for the most relevant data sources, including the data input in ILWIS followed bybasic processing steps. All examples make use of data from Georgia.

Exercise *2-A* : MODIS satellite data, with examples from the MODIS Surface Reflectance Product and MODIS/AQUA Global Snow Cover Monthly Product

Exercise 2-B : **Landsat MSS, TM and ETM data** from the CGIAR Consortium for Spatial Information

Exercise 2-C : **Shuttle Radar Topography Mission Elevation Data (SRTM)**

Exercise 2-D : **Aster GDEM elevation data** from the Japanese Space Systems website

Exercise 2-E : **Global METEO data** from the European Climate Assessment dataset

Advice Each participant can choose to download one or two data types. It is recommended to work in groups of 2 to 3 people, of which each person works on his/her own data.

It is highly recommended to read the descriptions of the data to be downloaded from the internet sites.
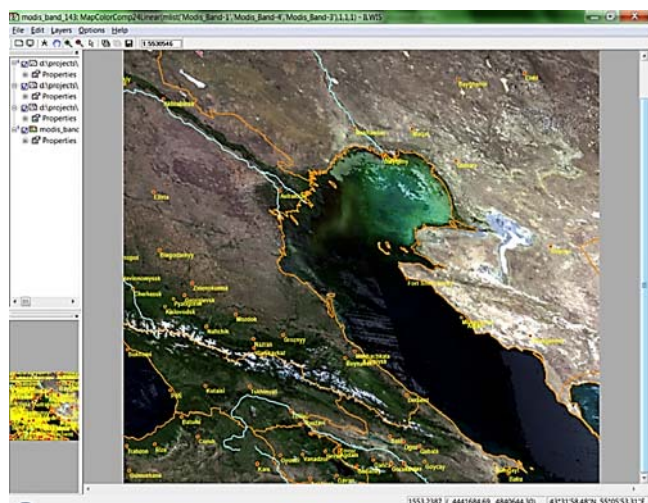
2.2 SEARCH & DOWNLOAD MODIS IMAGERY USING REVERB PORTAL

2.2.1 Example 1: MODIS Surface Reflectance product

MODIS	REVERB Website for download		Description of MODIS
	http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93 &spatial_map=satellite&spatial_type=rectangle		http://modis.gsfc.nasa.gov/about/
DATA	**FORMAT**	Description	
MOD09A1.A2..........	HDF	Downloaded MODIS image of 26 June - 02 July 2013 Surface reflectance	
Country_Boundaries	ILWIS Shape	Global dataset of the boundaries of all countries	
Cities	ILWIS Point	Global dataset of the main cities	
Rivers	ILWIS Shape	Global dataset of the main rivers	

There are many different image modes of MODIS. For this exercise we download the MODIS Surface-Reflectance Product (MOD 09) using visible land bands 1, 2, 3, 4, 5, 6 and 7, at a resolution of approx. 500 meter. This product is an estimate of the surface spectral reflectance of each band as it would have been measured at ground level if there were no atmospheric scattering or absorption during an 8-day period as selected on the basis of among others absence of clouds or cloud shadow.

Detailed instructions for search and download of MOD09:

- Open the MODIS Web Portal : http://modis.gsfc.nasa.gov/data/
- Select: **+ABOUT MODIS** Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. Read - if you wish - some additional background text.
- Open : **+Specifications** to see the properties of the sensor for different types of applications. The image bands 1 to 7 of the Terra platform are the best for monitoring the land surface.
- To download MODIS data you select the hyperlink **MODIS Land Products** in **+Data** : https://lpdaac.usgs.gov/
- Select: **Data Access** under **Welcome** (left pane) to guide you through the steps needed to acquire the satellite images. As you see there are different Web Portals to download data. We use for now the **Reverb** portal.
- Select: **Launch Reverb:** http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type =rectangle
- **Sign** In **first** (upper right site). Select: **Need an EOSDIS user account?** Follow the instructions and fill in all the on-line forms for this. At the end of the registration procedure you will receive an email for confirmation. This will take a couple of minutes.
- After you have Signed In
- Select for **Search Options: Platforms:** TERRA, **Instruments:** MODIS, **Sensors:** MODIS

- Step 1 **Search criteria**:

- o Spatial search: Click and drag in the World Map to set for the selection a bounding rectangle. Select for this exercise only a small area, for instance the country of Georgia. Use the **Help** function if needed.
  - o Search Terms: Type: **MOD09A1**
  - o Temporal Search: Select the start and end data. For the exercise for instance the summer period of 2013.
  - o We leave the other search options open.
  - o Safe the Query if you want to keep it (lower left side of pane).
- Step 2 **Select datasets:**
  - o Select the dataset by clicking the box, for instance for MOD09A1:
    MODIS/Terra Surface Reflectance 8-Day L3 Global 500m SIN Grid V005
- Step 3: **Discover granules:**
  - o Check the granules you have selected in Step 2
  - o Select: **Search for Granules.** After some time a (long) list of granules will be displayed with granule ID, Start time and End time
    - ▪ Look at the Quick-looks (if available)
    - ▪ Study the image information
    - ▪ Add the selected granules to your cart
- Select: **View items in Cart**
  - o Check in the shopping cart if the scenes are orderable (Yes)
  - o Select: **Order**
  - o Check your contact information. If done, select: **Proceed**
  - o In Order Items: **Set** the **Media Type**: **HTTP Pull** and **Safe.** If done: **Proceed.**
  - o Select: **Submit Order.** After this you will receive various emails with confirmations of your order. In the mail with in the header **CM SHARED** you are given the Link to download the data file(s) in HDF format. This can take some time.
  - o Unzip the file for further processing.

Detailed instructions for Import MOD09 in ILWIS 3.3 (Academic):

Import of the MODIS scenes with HDF file format is possible with various softwares, such as ERDAS Imagine, ArcGIS, ENVI etc. Also freeware can be downloaded from
https://lpdaac.usgs.gov/
For import in the ILWIS software one should use for this **Version 3.3** (**Academic**) with the GeoGateway Plug In (Remark: In later ILWIS versions this plug-In has been removed for licencing reasons).

Instructions:
- Install ILWIS 3.3
- Select: *File, Import, Via GeoGateway*
- Select the downloaded MODIS09 file with HDF extension

Remark: For the exercise you can also use the already downloaded MODIS scene of 26 June - 02 July 2013 : MOD09A1.A2013177.h21v04.005.2013186130806.hdf

- Type the **Output Filename**

- Select the box: **Convert to ILWIS data format**. After input an *Object Collection* icon will be displayed with the Filename.

- Click the **Object collection** icon to open all raster icons of the 12 MODIS image bands.
- Look in the properties of the scenes, such as extent, pixel size, min & max value etc. by: *Right mouse-clicking* the raster icon and selecting: **Properties.**

Instructions of the **<u>display</u>** of a MODIS09 natural color image in ILWIS Ver 3.4

- To display one band of MODIS double click the raster icon and select : Representation: FINEGRAY. After this: OK.
- Browse with the mouse cursor through the image. You will see that different gray tones will have different pixel values.
- To get an idea about the distribution of the pixel values: Display the image histogram by double-clicking the Histogram icon.
- To display a color composite image with near natural colors, we first have to linear stretch the individual image band to a 0 – 255 value range (Image Domain) by: Right mouse-click the raster icon of the image band: *Image Processing, Stretch…*
  - o Stretch Method: **Linear Stretching**
  - o Stretch from: **Percentage : 1.00**
  - o Domain: **Image**
  - o Type the **Output Raster Map** name
- For the creation of a color composite you select: *Operations, Image Processing, Color Composite*. Select the **Red**, **Green** and **Blue** image bands according to the below table. After this type the name of the **Output Rastermap** and if done select: *Show*.
- Browse the color composite, zoom in / out and try other band combinations too.
- Overlay the image with the **Global Dataset** of Country Boundaries, Cities and Rivers

Band	Wavelength (nm)	Description
Band 1	620-670	Red
Band 2	841-876	Near-infrared
Band 3	459-479	Blue
Band 4	545-565	Green
Band 5	1230-1250	Short wave infrared
Band 6	1628-1652	Short wave infrared (similar to Landsat band 5)
Band 7	2105-2155	Short wave infrared (similar to Landsat band 7)

2.2.2   Example 2: MODIS/Aqua Global Snow Cover

	REVERB Website for download	Description of MODIS
MODIS	http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93 &spatial_map=satellite&spatial_type=rectangle	http://modis.gsfc.nasa.gov/about/

DATA	FORMAT	Description
MYD10CM.A2011..........	HDF	Downloaded MODIS image of 26 June - 02 July 2013 Snow cover
Country_Boundaries	ILWIS Shape	Global dataset of the boundaries of all countries
Cities & Rivers	ILWIS Point	Global dataset of the main cities

There are many different image modes of MODIS. For this exercise we download the MODIS/Aqua Snow Cover Product of one month period (MYD10CM) which is available globally at a resolution of approx. 0.05 Deg.

Detailed instructions for search and download of MYD10CM**:**

- Open the MODIS Web Portal : http://modis.gsfc.nasa.gov/data/
- Select: **+ABOUT MODIS** Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. Read - if you wish - some additional background text.
- Open : **+Specifications** to see the properties of the sensor for different types of applications. The image bands 1 to 7 of the Terra platform are the best for monitoring the land surface.
- To download MODIS data you select the hyperlink **MODIS Land Products** in **+Data** : https://lpdaac.usgs.gov/
- Select: **Data Access** under Welcome (left pane) to guide you through the steps needed to acquire the satellite images. As you see there are different Web Portals to download data. We use for now the **Reverb** portal.
- Select: **Launch Reverb:** http://reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type =rectangle
- Sign In first (upper right site). Select: **Need an EOSDIS user account?** Follow the instructions and fill in all the on-line forms for this. At the end of the registration procedure you will receive an email for confirmation. This will take a couple of minutes.

After you have **Signed In** follow the following Steps:

- Step 1 **Search criteria**:
    - o Spatial search: As we are search for a global dataset it is not necessary to set a specific area.
    - o Platforms & Instruments: Platform: Aqua / Instruments: MODIS / Sensors: MODIS
    - o Temporal Search: Select the start and end data. For the exercise for instance the winter period of the years 2012/2013.
    - o Search terms: MYD10CM
    - o We leave the other search options open.
    - o Safe the Query if you want to keep it (lower left side of the pane) .
- Step 2 **Select datasets**:
    - o Select the dataset, for instance
    - o MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG V005
- Step 3: **Discover granules**
    - o Check the granules you have selected in Step 2
    - o Select: **Search for Granules** After some time a list of granules will be displayed with Granule ID, Start time and End time
        - ▪ Look at the Quick-looks (not always available for global datasets)
        - ▪ Study the image information
        - ▪ Add the selected granules to your cart
- Select: **View items in Cart**
    - o Check in the shopping cart if the scenes are orderable.
    - o Select: **Order**
    - o Check your contact information. If done: **Proceed**
    - o In Order Items **: Set** the Order Options : Media Type: **HTTP Pull** and after this **Safe.** If done: **Proceed.**

- o   Select: **Submit Order.** After this you will receive various Emails with confirmations of your order. In the mail with in the header **CM SHARED** you are given the Link to download the data file(s) in HDF format. This can take some time.
- o   **Unzip** the file for further processing.

Detailed instructions for Import of MYD10CM in ILWIS 3.3 (Academic):

Import of the MODIS scenes with HDF file format is possible with various software, such as ERDAS Imagine, ArcGIS, ENVI etc. Also freeware can be downloaded from https://lpdaac.usgs.gov/
For import in the ILWIS software one should use for this **Version 3.3 (Academic)** with the GeoGateway Plug In (Remark: In later ILWIS versions this plug-In has been removed for licencing reasons).

Instructions:

- •   Install ILWIS 3.3
- •   Select: *File, Import, Via GeoGateway*
- •   Select the downloaded **MODIS09** file with **HDF** extension

Remark: For the exercise you can also use the already downloaded MODIS snow cover scene of April 2011 : MYD10CM.A2011091.005.2011123002919.hdf

- •   Type the **Output Filename**
- •   Select the box: **Convert to ILWIS data format**. After input an *Object Collection* icon will be displayed with the Filename.
- •   Click the *Object collection* icon to open all raster icons of the 12 MODIS image bands.
- •   Look in the *properties* of the scenes, such as extent, pixel size, min & max value etc. by: *Right mouse-clicking* the raster icon and selecting: **Properties.**

Display of MODIS Snow cover image in ILWIS

- •   To display Band_1 with the snow data in ILWIS double-click the raster icon and select : *Representation:* **FINEGRAY**. After this: **OK**.
- •   Browse with the mouse cursor through the global image and after this zoom in to Georgia. You will see that cells with different gray tones have different pixel values.
- •   To get an idea about the distribution of the pixel values: Display the image histogram of Band_1 by double-clicking the *histogram icon*. The percentage of snow cover per cell is given in the values 0 – 100

- •   To display only the cells with the percentages snow cover, you type in the *Command line* the following MapCalc formula:

  MODIS_GlobalSnow_Apr11:=iff(*MapName* <101,*Mapname*,?)

Cell value	Description
0 - 100	Percentage of snow in cell
211	Night
250	Cloud
253	No decision - unclassified
254	Water Mask
255	Fill

- •   Display the newly made image with Representation: **Precipitation 1** . Browse through the image. Overlay the image with the **Global Dataset** with Shapefile data with Country Boundaries and Cities.
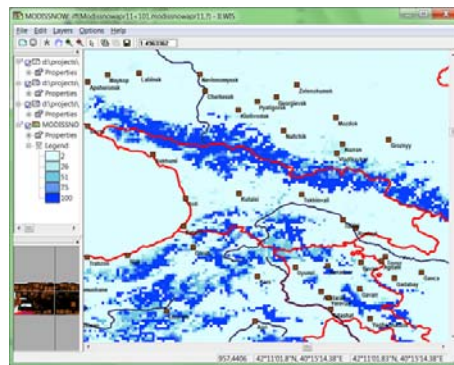
2.3   DOWNLOAD AND IMPORT OF LANDSAT SATELLITE DATA

2.3.1   Example 1: Landsat data from Global Land Cover Facility

Various aerospace data can be downloaded for free from the Global Land Cover Facility
website: http://glcf.umiacs.umd.edu/index.shtml

This are among others very useful older LANDSAT
satellite data. Please note that images from the
Landsat-7 sensor have some striping and are therefore
not very suitable for download.

For the most recent Landsat data (year 2013) you have
to go to the Earth Explorer website of the USGS.
Instructions for this are given on the next page of the
handout.
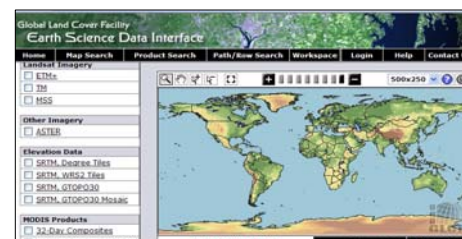
All Landsat can be downloaded in GeoTiff with UTM WGS84.

In this exercise an example is given on how to download a Landsat ETM data of Georgia. In
case your internet connection is not so fast, you can also use the already downloaded example
Landsat ETM data file of the Mt. Kazbegi area in GeoTif.

Downloaded and unzipped data can be imported directly into the ILWIS program. Further
processing can be carried out in the Image Processing module of ILWIS.

	Website for download	Description of Landsat data
Landsat	*http://glcf.umiacs.umd.edu/index.shtml*	*http://landsat.usgs.gov/*
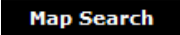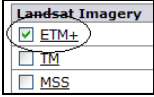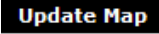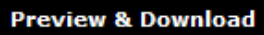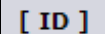
DATA	FORMAT	Description
Landsat TM_31Aug99	TIF	In the folders North and South: : All downloaded bands from the GLCF website. Date: 31 August 1999
Georgia – coord system	ILWIS	Coordinate system projection – UTM WGS84 - Zone 38
Kazbegi_Contours	ILWIS	Subset Topographic Contourlines of Georgia, 1:50:000 scale
Country_Boundaries	ILWIS Shape	Global dataset of the boundaries of all countries
Cities	ILWIS Point	Global dataset of the main cities
Rivers	ILWIS Shape	Global dataset of the main rivers

Detailed instructions for download from the **Global Land Cover Facility** (**GLCF**) website:

- Browse to the **GLCF website**: *http://glcf.umiacs.umd.edu/index.shtml*

- Select **Download Data**

- Select **Map Search** Map Search

  Landsat Imagery
  ☑ ETM+
  ☐ TM
  ☐ MSS

- Select: **Landsat Imagery : ETM+**
- Remark: You can also choose **TM** or **MSS** if you wish.
- Click to select the available images ⌜⌟
- Select: **Update Map** Update Map The available image scene footprint covering the selected area will become red
- Select: **Preview and Download** Preview & Download
- Click image by image the ID [ID] and look at the image footprint and Quick look.
- Select: **Download** Download
- A list is displayed with downloadable individual image bands, quick-looks and a metadata file (*.met).
- Download the metadata file first. You can do this by: Right-mouse clicking, *Save target as…*
- Task: Open the metadata file with <u>MS Word</u> and study the contents, such as image band names, date of acquisition, pixel size, etc.
- Download also the other bands in your data folder by Right-mouse clicking, *Save target as…*
- <u>Advice</u>: first download the bands 2, 3 and 5. With this image bands it will already be possible to create a nice color composite image.
- **UNZIP** all data.

2.3.2 Example 2: Landsat data from GLOVIS

Detailed instructions for download from the **USGS Global Visualization Vieuwer** (GLOVIS)

- Browse to the **GLOVIS website: http://glovis.usgs.gov/**
- Activate **JAVA** software to display the map interface
- To browse for the most recent Landsat imagery (year 2013) of the <u>Operational Land Imager</u> select: *Collection, Landsat Archive, Landsat 8 OLI*
- Click with the cursor in the <u>World map</u> at the location of your area of interest. The software will zoom in automatically to the available Landsat images.
- Click with the mouse in the displayed area to see available Landsat scenes, indicated with a yellow line
- If needed change the display resolution by: *Resolution, 240m*
- Add map layers by: *Map Layers, All Map Layers* (or a selection only)
- For other available dates : Click the buttons : **Previous Scene** or **Next Scene**
- If you wish to download the selected scene: click the button Add (lower left pane)
- Select: **Send to Cart**
- **Log In** first or **Register** to the Website

- Click the Download icon:
- Select one of the Bulk Products:
  - LandsatLook "Natural Color" Image – <u>First choice !</u> <5 Mb - Dowloads all bands
  - LandsatLook "Thermal" Image
  - LandsatLook "Quality" Image
  - LandsatLook images with Geographic Reference
  - Level 1 GeoTIFF Data Product – Best geometric Quality, but almost 900 Mb of Data
- **Download** the select data product and **UNZIP**

2.3.3   Import and display of Landsat data in ILWIS 3.4

The downloaded individual image bands in GeoTIF data format in 8 bit from GLCF can be easilt imported in the ILWIS program. The Landsat data from GLOVIS is 16 bit and need extra processing before import in ILWIS.
After import the bands can be combined to a color composite display. The instructions are for ILWIS Version 3.4.

Remark: You can use for this exercise also the already Landsat Thematic Mapper files of 31 August 1989 (North and/or South area Mt. Kazbegi, Georgia)

Detailed instructions for import of **8 bit** Landsat data:
- Make clear that all the data are **UNZIPPED** !
- Open the **ILWIS program**.
- Browse with the Navigator to the folder with the downloaded and Unzipped Landsat data.
- Select in the *ILWIS Main* menu: *File, Import, Via GDAL*
- Select in the *Import* window one of the ***.TIF** files; type the **Output File name**. Add the image band number in the file name. Example: for Landsat TM band 3: ETM_b3. If done: **OK**.
Remark: For the exercise indicate in the output filename also the location, year of acquisition and whether the scene is from the North or from the South. For instance: Kazbegi_TM89_N_B5

- Do the same for the other Unzipped Landsat ETM image bands as well.
- Display the *Properties of Raster* window of one of the image bands (to do this: *right mouse-click* the raster icon). You will see that the Pixel Size is 28.5 meter and the *Domain*: **VALUE**. For further image processing of the Landsat bands in ILWIS, they have to be given a *Domain*: **Image**.
- Select in the *Properties of Raster* window for the first image band in the drop-down list *Domain*: **IMAGE**. If done select: *Apply, OK*. Repeat this for all the other image bands.
- To display a Color composite select: in the *ILWIS Main* menu: *Operations, Image Processing, Color Composite*.
- Select in the *Color Composite* window the following image bands:
- *Red Band* : **TM_b5** / *Green Band*: **TM_b3** / *Blue Band*: **TM_b2**
- Type the *Output Raster Map* name: **ETM_b532**
- Leave all the other values, such as Linear Stretching, Percentage and RGB in default
- If done select: **SHOW**
- Browse the image and zoom in to certain areas

2.3.4   Example: Creating a subset using Landsat TM scenes

Landsat Thematic Mapper scenes of 1989 have been downloaded from the Northern and Southern parts of the Kazbegi mountains, Georgia. These scenes are largely cloud free except some spots in the highest parts of the mountains (of more recent Landsat scenes, such as Landsat Enhanced TM - this is unfortunately not always the case). This is the reason that we use for the exercise this relatively old TM imagery.

By matching both scenes, an almost cloud free coverage of the Kazbegi area can be made. To combine the Northern and Southern scene to one image, we have first to glue both scenes to one large scene. This can be done by resampling the scenes to the provided Geo-reference of the Kazbegi mountains (Pixel size : 30m).

Detailed instructions:

- Select in the *ILWIS Main* menu: *Operations, Raster Operations, Glue Maps*
- Select in the *Glue Raster Maps* window*:*
       1st Map: **Northern Landsat TM Scene band 1**
       2nd Map: **Southern Landsat TM Scene band 2**
- *Geo-Reference:* **Kazbegi_30m**
- Type the **Output Raster Map** name
- Select: **Show**
- Repeat this for the other image bands
- Create a color composite (see instructions above in paragraph 3.3.3)
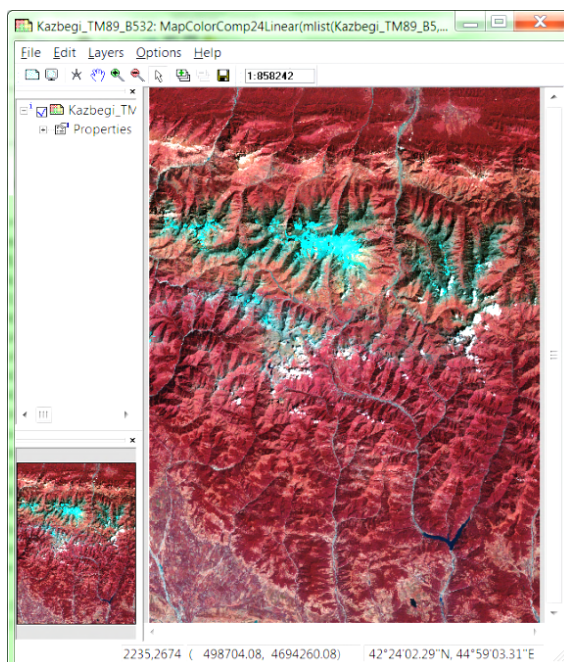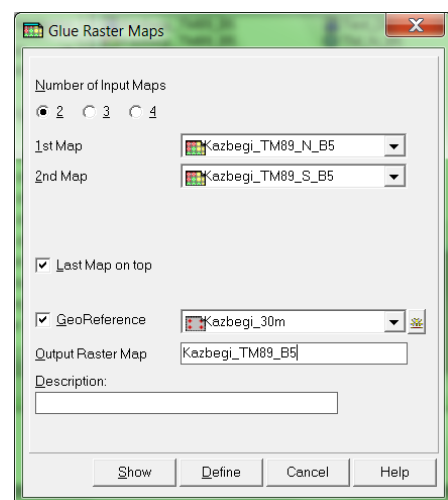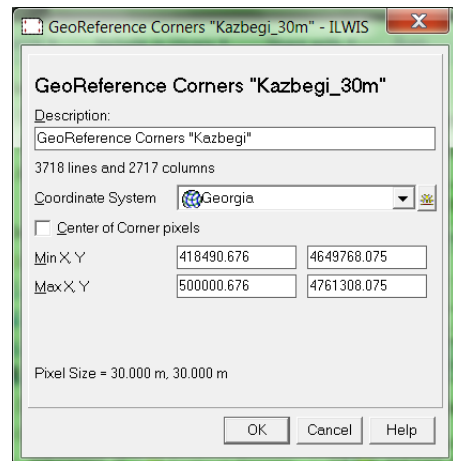
2.4   DOWNLOADING AND PROCESSING SRTM ELEVATION DATA

We will demonstrate the download of SRTM from the CGIAR Consortium for Spatial Information: **http://srtm.csi.cgiar.org/**

The procedure is as follows: (1) First you select the SRTM tile to be downloaded on a global map; (2) after this you download the data. All data is in raster format; global SRTM has a pixel size of 3 ArcSeconds (approx. 91 by 91 meters).
The data, after being unzipped can be imported directly into the ILWIS program.
Further processing can be carried out in the Hydro -DEM modeling module of ILWIS. In this module we can make a special color hill-shade, with good terrain expression.

The SRTM data file has to be downloaded from the **CGIAR-CSI Website** in blocks of 5 x 5 degrees. Please note that the GeoTIFF data has an extension tif (so, without "Geo"). This file has WGS 84 with Lat. / Long. Coordinates. Make sure that the ***.tif** file has the header file and ***.tfw** file attached to it.

	Websites for download	Description of SRTM
SRTM	*http://srtm.csi.cgiar.org/*	http://srtm.csi.cgiar.org/SRTM_FAQ.asp

DATA	FORMAT	Description
SRTM_45_04.ZIP	TIF	Already downloaded SRTM of a part of Georgia
Georgia – coord system	ILWIS	Coordinate system projection – UTM WGS84 - Zone 38
SRTM_WestGeorgia	ILWIS	Georeference of the SRTM_45-04
Kazbegi_90m	ILWIS	Georeference of the Kazbegi area with pixels 90m.
Kazbegi_Contours	ILWIS	Subset Topographic Contourlines of Georgia, 1:50:000 scale
Kazbegi_TM89_b5	ILWIS	Landsat TM Band 5 of 31 August 89
Country_Boundaries	ILWIS Shape	Global dataset of the boundaries of all countries
Cities	ILWIS Point	Global dataset of the main cities
Rivers	ILWIS Shape	Global dataset of the main rivers

2.4.1   **Downloading of SRTM data**

Detailed instructions for download of SRTM from CGIAR-CSI:
- Browse to the **CGIAR-CSI** website: *http://srtm.csi.cgiar.org/*
- Select under *SRTM Content*: **SRTM Data Search** and **Download**
- First you have to select the server to download from, the Data Selection Method and the File Format. Remark: Try first the server **JRC (IT)**, which gives also the header files for the WGS84 Datum.
- You start with the following options (later you can try different ones):
  - *Server:* **JRC (IT)**
  - *Data Selection Method*:
     1. **Enable Mouse Drag** and select one or more tiles on the map

2. **Input Coordinates** (Decimal Degrees or Degrees, Minutes, Seconds)
    Type for Longitude and Latitude the Min. and Max. values.
- Select *File Format*: **GeoTIFF**
- If done select the **Yellow box**: Click here to **Begin Search**. A next webpage opens with Quick-looks and image information of the selected area(s). Check the areas you want to download.
- Select for the tile(s): Data Download (FTP).
- Select: Save File in the File Download window. Create a folder for all the SRTM data tiles and copy the data you want to this folder.
- UNZIP the tile data. Make sure that not only the *tif file, but also the files *.hdr and *.tfw are given.

Remark: Unfortunately this is not always the case with TelaScience (USA) and GDevSolutions. Therefore use Server JRC IT first.

- Open the ***hdr** file with <u>MS Word</u>. Read the details of the SRTM data.

2.4.2   **Import, georeference and resample SRTM data in LWIS 3.4**

Import of SRTM

The downloaded GeoTIFF data can be easily imported in the ILWIS program. The resulting file will still have Lat / Long coordinates and a pixel size of 3 Arc Seconds, corresponding to approx. 90 meters.

<u>Detailed instructions :</u>

- Open the **ILWIS program**
- Browse with the *Navigator* to the folder with the downloaded and unzipped SRTM Data

> **Remark**: One can also use for this the already downloaded data file of the Western part of Georgia: **SRTM_045_04.ZIP**

UNZIP the downloaded data file !!
- Select in the *ILWIS Main* menu: *File, Import, via GDAL*
- Select : the downloaded TIF file (also <u>NOT</u> the files with other formats !!)
- Type the **Output Filename** and after this: Select: **OK**
- Display the SRTM by double clicking the *Raster Map* icon. Select in the *Display – Raster map* window:
    O *Representation*: **Elevation 1.**
    O *Check Box*: **Info**
    O *Stretch*: **Linear**
    O Leave all other values default
    O If done: **OK**

- Browse with the cursor through the display of the SRTM. The values are in meters altitude.
- Click the *Histogram icon* of the imported SRTM. Study the distribution of the elevations in meters.
- Select: *Properties of Raster* map and check the Pixel size and the Corner Coordinates. The pixel size and Coordinates are still in degrees and not yet in UTM WGS84 with meter values. The Domain should be Value.
- Overlay the downloaded SRTM with the **Global Data** with Country Boundary file Cities file and Rivers file.

Creation of a Coordinate system

The downloaded data of the SRTM is in Lat/Long format, with a pixel size of 3 Arc Seconds, corresponding with a UTM coordinate system pixel size of approx. 90 meters. Therefore after import a UTM WGS coordinate system have to be made (or another local type) and secondly the pixels have to be resampled to 90 meter. To do this, you do first have to create the new coordinate system and a ILWIS Geo-Reference.

Remark: In case you want to skip this part of the exercise, you can use the coordinate system : Georgia and the Geo-Reference : SRTM_WestGeorgia.

Detailed instructions:

- Select in the *ILWIS Main* menu: *File, Create, Coordinate System…*
- Select or type in the *Create Coordinate* System window:
  - *Coordinate System*: **Projection**
  - Type the Coordinate system name
  - If done: **OK**
- Select in the *Coordinate System Projection* window:
  - *Tab Projection*: select: **UTM**, if done **OK**
  - *Tab Ellipsoid*: select: **WGS 84**, if done: **OK**
  - *Tab Datum*: select: **WGS 1984**, if done: **OK**
  - Fill in the UTM zone for the Northern Hemisphere for Georgia
    You can find a list with UTM zone zones by searching **ILWIS Help** (or the table next page below). Search for *Projections*: **UTM zones.**
- If done: **OK**

Remark: You can also choose to create another coordinate system, for instance that used by the national survey agency of your country.

Creation of a Geo-Reference

For the creation of a Geo-Reference one has to know the UTM coordinates of the corners of the image. To be able to fill the table below, one can use the ILWIS program Transform Coordinates.

Detailed instructions

- Select in the *ILWIS Main* menu: *Operations, Vector Operations, Coordinates, Transform Coordinates*
- Select the **Input Coordinate System** (the one of the SRTM in Lat/Long)
- Select the **Output Coordinate System** (the one you created before)

- Fill in the Table:

	Latitude (N/S)	Longitude (E/W)	UTM X (Zone ……..)	UTM Y (Zone ……..)
Top Left corner				
Bottom Right corner				

- Now select in the *ILWIS Main* menu: *File, Create, GeoReference*.
- Select or type in the *Create GeoReference* window:
  - GeoRef Corners
  - Type the GeoReference name
  - Select Coordinate System (the one you created)
  - Type the Pixel size: 90 (meters)
  - Type the Min X,Y and Max X,Y coordinates in UTM of the study area
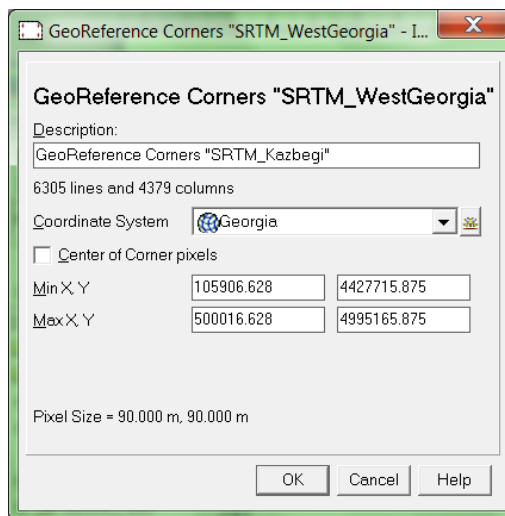
Resampling of the SRTM dataset to the created GeoReference with pixels of 90 m.

Detailed instructions:

- Select in the *ILWIS Main* menu:
  Operations, Image processing, Resample.
- Select or type in the *Resample Map* window:
  - *Raster Map*: select the downloaded SRTM file in Lat / Long
  - *Resampling Method*: **Bicubic**
  - Type the name of the **Output Raster Map**
  - GeoReference: select the one you created before
- If done: **OK**
- Display the newly created SRTM. Check the Properties.

UTM ZONES							
UTM zone code	Long. centr. merid.	Long. range from:	Long. range to:	UTM zone code	Long. centr. merid.	Long. range from:	Long. range to:
1	-177	-180	-174	31	3	0	6
2	-171	-174	-168	32	9	6	12
3	-165	-168	-162	33	15	12	18
4	-159	-162	-156	34	21	18	24
5	-153	-156	-150	35	27	24	30
6	-147	-150	-144	36	33	30	36
7	-141	-144	-138	37	39	36	42
8	-135	-138	-132	38	45	42	48
9	-129	-132	-126	39	51	48	54
10	-121	-126	-114	40	57	54	60
11	-117	-120	-114	41	63	60	66
12	-111	-114	-108	42	69	66	72
13	-105	-108	-102	43	75	72	78

14	-99	-102	-96	**44**	81	78	84
15	-93	-96	-90	**45**	87	84	90
16	-87	-90	-84	**46**	93	90	96
17	-81	-84	-78	**47**	99	96	102
18	-75	-78	-72	**48**	105	102	108
19	-69	-72	-66	**49**	111	108	114
20	-63	-66	-60	**50**	117	114	120
21	-57	-60	-54	**51**	123	120	126
22	-51	-54	-48	**52**	129	126	132
23	-45	-48	-42	**53**	135	132	138
24	-39	-42	-36	**54**	141	138	144
25	-33	-36	-30	**55**	147	144	150
26	-27	-3-	-24	**56**	153	150	156
27	-21	-24	-18	**57**	159	156	162
28	-15	-18	-12	**58**	165	162	168
29	-9	-12	-6	**59**	171	168	174
30	-3	-6	0	**60**	177	174	180

2.4.3 Color-hillshade, subsetting and quality checking of SRTM

Creation of color-hillshade

A special color hill shade script for elevation data has been developed by Dr. Koert. Sijmons, ITC.

- I. In the script first three shadow maps are created using the shadow filters ShadowW (West), Shadow (North-West) and ShadowN (North).
- II. The three shadow maps are stretched using linear stretching.
- III. The color composite that is created from these stretched shadow maps is a 24-bit color composite.
- IV. Finally the temporal raster map are removed and the output color composite is being displayed

Detailed instructions creation color-hillshade:

- Select in the *ILWIS Main* menu: *Operations, DEM Hydro-Processing, DEM Visualization*
- Select in the *DEM Visualization* window your SRTM data; type the **Output File name**. If done: **OK**.

A script is used to create the color-hill shade. This can take some time.

- Open the **Output map** and check the result
- Overlay the hill-shade map with the **Global dataset** of Country boundaries, Cities and Rivers
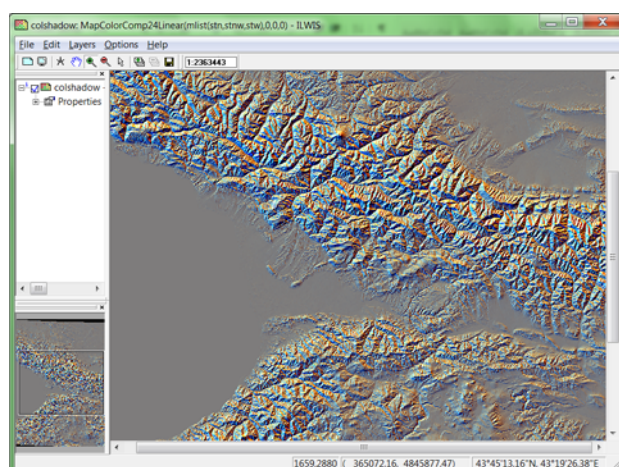
<u>Creation of color-hillshade</u>

Creation of a subset of SRTM (Kazbegi area)

Resampling of the SRTM data to the already created GeoReference of the Kazbegi area with pixels of 90 m.

Detailed instructions:

- Select in the *ILWIS Main* menu: Operations / Image processing / Resample.
- Select or type in the *Resample Map* window:
    - *Raster Map:* select the downloaded SRTM file
    - *Resampling Method*: **Bicubic**
- Type the name of the **Output Raster Map**
- *GeoReference:* **Kazbegi_90m.**
- If done: **OK**
- Display the newly created GDEM. Check the Properties**.**

Checking the SRTM elevation values with the topographic contour line data scale 1:50.000

Detailed Instructions:

- Display the rectified SRTM
- Select in the *Display* window: *Layers, Add Layers, Kazbegi_contours*
- Select in the *Display Options – Segment Map* window : *line width* : **3** and an appropriate *Representation*
- Zoom-in to individual contour lines and check with the mouse-curser the elevations and the positions of the lines relative to the SRTM of the area with the contour lines.

Question: What are your conclusions about the accuracy?

…….

It will be may be better to make a new Digital Elevation Model from the Kazbegi contour lines by interpolation and checking again this with the SRTM data.

Detailed Instructions:

- Select in the *Main ILWIS* window: *Operations, Interpolation, Contour Interpolation*
- Select in the *Contour Interpolation* window;
    - *Contour map* : **Kazbegi_contours**
    - *Output Raster map* : **Kazbegi_ContourDEM**
    - *Georeference* : **Kazbegi** (the one you created before)
    Suggestion: You can also use the given Georeference Kasbegi_30m.
    - *Domain:* **Value**
    - *Precision* : **1.0**
    Select: **Show**
- Open in the *Main ILWIS* window: **Pixel Information**
- Select in the *Pixel Information* window: *File, Add Map*

- o   Add the SRTM in UTM WGS84 and the **Kazbegi_ContourDEM**
- Browse through the DEM with your cursor and compare the elevation values of both DEMs.

Question: What are your conclusions about the accuracy? Where are the elevation differences between both of the DEMs the highest?

……

……

Another way of comparing both DEMs is to make a new elevation model of only the differences between the contour DEM and the Aster GDEM.

Detailed Instructions:

- Type on the command line of the *ILWIS Main* window:
     DEMDIFF:= Name of AsterGDEM – Kazbegi_DEM

Check the result and draw conclusions. You will see that the differences are at places very high. What can be the reason of this?

2.4.4   Creaton of topographical attribute maps of the SRTM data

A slope map can be created from the DEM with the following steps:

1. First one has to calculate from the DEM the height differences in X and Y directions. For this a linear filter can be used. The filter names are **dfdx** and **dfdy**. Name the output maps **DX** and **DY**.

   Instructions:
   - Select in the *ILWIS Main* menu: *Operations, Image Processing, Filter*
   - Select *Filter Type*: **Linear** and as *Filter Name*: **DFDX**
   - Type as *Output Raster Map*: **DX**
   - Do the same Linear filtering of the Y direction

2.   To calculate a **slope map** in percentages from these maps DX and DY on has to use a Map Calculation formula.

   Instructions:
   - Type on the *Command line* of the *ILWIS Main* window:
   -         **SLOPEPCT = 100 * HYP(DX,DY)/ PIXSIZE(DEM)**
             Explanation: HYP is an internal Map Calculation function.
             Function PIXSIZE returns the pixel size of a raster map;
   - For DEM, fill out the name of your DEM created before. **SLOPEPCT** is the name of the output map

   To convert the percentage values into degrees, type in the *Command line*:
             SLOPEDEG = RADDEG(ATAN(SLOPEPCT/100))
             Function **ATAN** and B are internal MapCalculation functions. **SLOPEDEG** is the output

map name of the slope map in degrees.

3. To calculate an **aspect** map in radians and degrees from the maps DX and DY follow the instructions:

- Type on the *Command line* of the *ILWIS Main* window:
  ASPECTR = ATAN2(DX,DY) + PI
- To convert the radians into degrees, type in the *Command line*:
  ASPECTD = RADDEG((ASPECTR))

2.4.5 Stereo of the Landsat TM Band-5 draped over SRTM.

The Stereo pair from DTM operation in the ILWIS program creates a stereo pair from a single raster image and a Digital Terrain Model (DTM). The (satellite) image will be displayed over the terrain.

The stereo pair can be viewed on the computer screen (split screen mode) with a stereoscope (screen-scope). or as an anaglyph using red-green or red-blue glasses.

Use of screen-scope   anaglyph glasses

In short, the process is as follows: First import the (satellite) image in ILWIS, including a geo-reference. Also import the DTM / DEM, which must have the same geo-reference as the image. The DTM can be created from (digitized) contour lines by interpolation. It is also possible to use an existing DEM, such as an Shuttle Radar Topography Mission Data (SRTM)DEM, ASTER GDEM or other DEM

Remark: The best quality you will get if the image and the DTM have approximately the same spatial resolution.

In ILWIS we use the "Stereo Pair from DTM" option for the operations. Rotation differences and possible scale differences between the image and the DTM / DEM will be removed.

Detailed instructions:

Stereoscopy: seeing of objects in three dimensions

1. Select in the *ILWIS Main* window: *Operations, Image Processing, Stereo Pair from DTM*
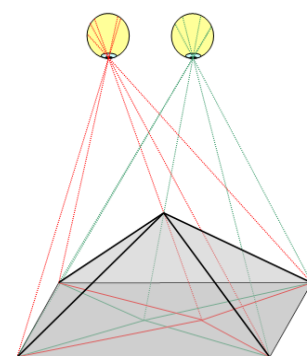
2. Select in the *Stereopair from DTM* window the Raster Map and the DTM. Use for both the subsets of the Kazbegi area. Select: **Show** to display the Stereo Image.

Now, both the DTM and the image will be re-sampled to Output maps, i.e. the stereo pair is calculated. Rotation differences and possible scale differences will be removed and the stereo--pair will appear on the screen.

3. *To show the stereo pair a next time on the computer screen, *right mouse-click* the stereo pair icon in the *Catalog*: . After this select: *visualization, with Stereoscope*

4. To create an Anaglyph image you have to repeat Step 3 by selecting: V*isualization, as Anaglyph..,*

Stereo viewing - Tips and hints

To properly view the stereo pair, you have to resize the Stereoscope window so that the horizontal distance between the left-hand and the right-hand photograph fits your eye base.

Make sure that the splitter between the left-hand pane and the right-hand pane in the Stereoscope window is in the middle of your stereoscope.

Make the Stereoscope window larger /smaller, by dragging a corner of the window.

When you use Zooming, Panning, Entire map or Redraw or when you scroll in one of the displayed photographs, this will be applied to both panes.

To move one or both photographs a little to the left or to the right, in order to improve stereo vision, you may unlock the left pane and right pane from each other.

2.5 DOWNLOADING AND PROCESSING OF ASTER GDEM ELEVATION DATA

Global Digital Elevation Data from the Aster Satellite can be downloaded for free from the **Japanese Space Systems** website: **http://gdem.ersdac.jspacesystems.or.jp/**

All data is in raster format; GDEM has a pixel size of 1 ArcSec (approx. 30 by 30 meters). After having downloaded the data, we will import the data into the ILWIS software and produce color hillshade maps. Finally from subsets topographic attribute maps will be made, such as of slope steepness and slope aspect.

	Websites for download	Description
GDEM	http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html http://gdem.ersdac.jspacesystems.or.jp	http://asterweb.jpl.nasa.gov/gdem.asp http://www.jspacesystems.or.jp/ersdac/GDEM/E/1.html

DATA	FORMAT	Description
ASTGTM2_42E044_dem	TIF	Already downloaded Aster GDEM of Mt. Kasbegi, Georgia
Aster_Kazbegi_VNIR	TIF	Aster VNIR iame of Mt. Kazbegi – UTMWGS84 – Zone 38
Georgia – coord system	ILWIS	Coordinate system projection – UTM WGS84 - Zone 38
Kazbegi_30m	ILWIS	Georeference of the ASTER-GDEM N42 E044 AND Landsat MS with pixels of 30m.
Kazbegi_Contours	ILWIS	Subset Topographic Contourlines of Georgia, 1:50:000 scale
Kazbegi_TM89_B5	ILWIS	Landsat TM Band 5 of 31 August 89
Country_Boundaries	ILWIS Shape	Global dataset of the boundaries of all countries
Cities	ILWIS Point	Global dataset of the main cities
Rivers	ILWIS Shape	Global dataset of the main rivers

2.5.1 Downloading of GDEM data

Detailed instructions:
- Browse to the **ERSDAC** website: *http://gdem.ersdac.jspacesystems.or.jp/*
- Login or **Register** first to get a personal password
- After Login select: **Search**
- Select: **Grid** and **zoom in** to your area of interest
- Select: **Tiles directly**
- Select: **Start**
- Select: **One or more tiles** (Remark: Start with one or tiles only to try things out)
- Select: **Next**
- Check yourself in the Tile List the Location Coordinates
- If OK select: **Next**
- Select: **Agree to accept the agreement**; Purpose: **Disaster**
- Select: **Download**
- Safe the file to a folder of your choice

2.5.2   Import, Georefere and Resample of GDEM data in ILWIS

Import of GDEM into ILWIS 3.4

GeoTIFF data can be easily imported in the ILWIS program. The resulting file will still have Lat / Long coordinates and a pixel size in degrees corresponding with approx. 30 meters.

Detailed instructions:

- Open the ILWIS program
- Browse with the Navigator to the folder with the downloaded and unzipped GDEM Data

Remark: One can also use for this the already downloaded data file of Mount Kazbegi,

Georgia: ASTGTM2_N42E044

- **UNZIP** the downloaded data file !!
- Select in the *ILWIS Main* menu: *File, Import, ILWIS*
- Select : **Raster**
- Select: **Tagged Image File format**
- Input: **Aster GTM2_xxxxxx_DEM**
- Output: default Click: **OK**
- Display the GDEM by double clicking the *Raster Map* icon. Select in the *Display –*
- *Raster map* window:
  - O *Representation*: **Elevation 1.**
  - O *Check Box:* **Info**
  - O *Stretch: Linear*
  - O Leave all other values default
- If done: **OK**
- Browse with the cursor through the display of the GDEM. The values are in meters altitude.
- Click the *Histogram* icon of the imported GDEM. Study the distribution of the elevations in meters.
- Select: *Properties of Raster* map and check the **Pixel size** and the **Corner Coordinates**.

Remark: The pixel size and Coordinates are still in degrees and not yet in UTM WGS84 with meter values. The Domain should be Value.

- Overlay the downloaded GDEM with the global country boundary file. You will see that the boundary runs along the highest areas of the Kasbegi mountain chain.

Georeferencing of GDEM to UTM WGS84

The downloaded data of the GDEM is in Lat/Long format, with a pixel size of 1 Arc Seconds, corresponding with a UTM coordinate system pixel size of approx. 30 meters. Therefore after import a UTM WGS coordinate system have to be made (or another local type) and the pixels have to be resampled to 30 meter. To do this, you do first have to create the new coordinate system and a ILWIS Geo-Reference.

Remark: In case you want to skip this part of the exercise, you can use the *coordinate system* : **Georgia** and the *Geo-Reference* : **Kasbegi_30m**

Detailed instructions – Creation of a UTM WGS84 coordinate system:

- Select in the *ILWIS Main* menu: *File, Create, Coordinate System…*
- Select or type in the *Create Coordinate System* window:
    o **Coordinate System Projection**
    o Type the **Coordinate system name**
- If done: **OK**
- Select in the *Coordinate System Projection* window:
    o *Tab Projection*: select: **UTM**, if done **OK**
    o *Tab Ellipsoid*:   select: **WGS 84**, if done: **OK**
    o *Tab Datum*:   select: **WGS 1984**, if done: **OK**
    o Fill in the UTM zone for the **Northern Hemisphere**
    You can find a list with UTM zone zones by searching **ILWIS Help** (or the table below). Search for **Projections: UTM zones.**
- If done: **OK**

Remark: You can also choose to create another coordinate system, for instance that used by the national survey agency of your country.

UTM ZONES							
UTM zone code	Long. centr. merid.	Long. range from:	Long. range to:	UTM zone code	Long. centr. merid.	Long. range from:	Long. range to:
1	-177	-180	-174	**31**	3	0	6
2	-171	-174	-168	**32**	9	6	12
3	-165	-168	-162	**33**	15	12	18
4	-159	-162	-156	**34**	21	18	24
5	-153	-156	-150	**35**	27	24	30
6	-147	-150	-144	**36**	33	30	36
7	-141	-144	-138	**37**	39	36	42
8	-135	-138	-132	**38**	45	42	48
9	-129	-132	-126	**39**	51	48	54
10	-121	-126	-114	**40**	57	54	60
11	-117	-120	-114	**41**	63	60	66
12	-111	-114	-108	**42**	69	66	72
13	-105	-108	-102	**43**	75	72	78
14	-99	-102	-96	**44**	81	78	84
15	-93	-96	-90	**45**	87	84	90
16	-87	-90	-84	**46**	93	90	96
17	-81	-84	-78	**47**	99	96	102
18	-75	-78	-72	**48**	105	102	108
19	-69	-72	-66	**49**	111	108	114
20	-63	-66	-60	**50**	117	114	120
21	-57	-60	-54	**51**	123	120	126
22	-51	-54	-48	**52**	129	126	132
23	-45	-48	-42	**53**	135	132	138
24	-39	-42	-36	**54**	141	138	144
25	-33	-36	-30	**55**	147	144	150
26	-27	-3-	-24	**56**	153	150	156
27	-21	-24	-18	**57**	159	156	162
28	-15	-18	-12	**58**	165	162	168
29	-9	-12	-6	**59**	171	168	174
30	-3	-6	0	**60**	177	174	180

Creation of a Geo-Reference

For the creation of a Geo-Reference one has to know the UTM coordinates of the corners of the image. To be able to fill the table below, one can use the ILWIS program Transform Coordinates.

Detailed instructions

- Select in the *ILWIS Main* menu: *Operations, Vector Operations, Coordinates, Transform Coordinates*
- Select the **Input Coordinate System** (the one of the GDEM in Lat/Long)
- Select the **Output Coordinate System** (the one you created before)
- Fill in the Table:

	Latitude (N/S)	Longitude E/W)	UTM X (Zone ....)	UTM Y (Zone ....)
Top Left corner				
Bottom Right corner				

- Now select in the *ILWIS Main* menu: *File, Create, GeoReference*.
- Select or type in the *Create GeoReference* window:
  - **GeoRef Corners**
  - Type the GeoReference name
  - Select Coordinate System (the one you created)
  - Type the Pixel size: **30** (meters)
  - Type the **Min X,Y** and **Max X,Y** coordinates in UTM of the study area from the table above.
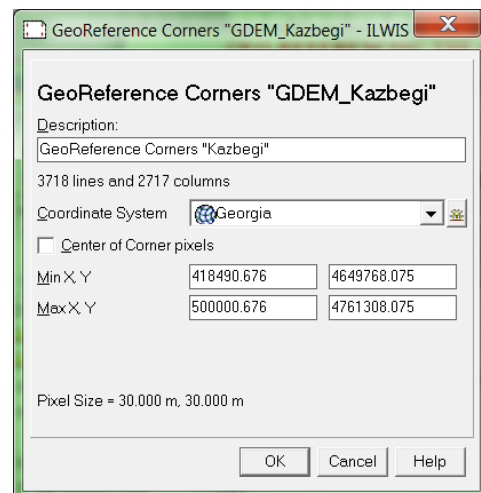
Resampling of the GDEM dataset to the created GeoReference with pixels of 30 m.

Detailed instructions:

- Select in the *ILWIS Main* menu: *Operations, Image processing, Resample.*
- Select or type in the *Resample Map* window:
  - *Raster Map*: select the downloaded GDEM file in Lat / Long
  - *Resampling Method*: **Bicubic**
  - Type the name of the **Output Raster Map**
  - GeoReference: select the one you created before (or the already available Georference : Kasbegi_30m)
- If done: **OK**
- Display the newly created GDEM. Check the Properties.

2.5.3   **Color-hillshade, subsetting and quality checking of GDEM**

Creation of color-hillshade

A special color hill shade script for elevation data has been developed by Dr. Koert. Sijmons, ITC.

V.	In the script first three shadow maps are created using the shadow filters ShadowW (West), Shadow (North-West) and ShadowN (North).
VI.	The three shadow maps are stretched using linear stretching.
VII.	The color composite that is created from these stretched shadow maps is a 24-bit color composite.
VIII.	Finally the temporal raster map are removed and the output color composite is being displayed

Detailed instructions creation color-hillshade:

- Select in the *ILWIS Main* menu: *Operations, DEM Hydro-Processing, DEM Visualization*
- Select in the *DEM Visualization* window your GDEM data; type the **Output File name**. If done: **OK**.

A script is used to create the color-hill shade. This can take some time.

- Open the **Output map** and check the result
- Overlay the hill-shade map with the **Global dataset** of Country boundaries, Cities and Rivers
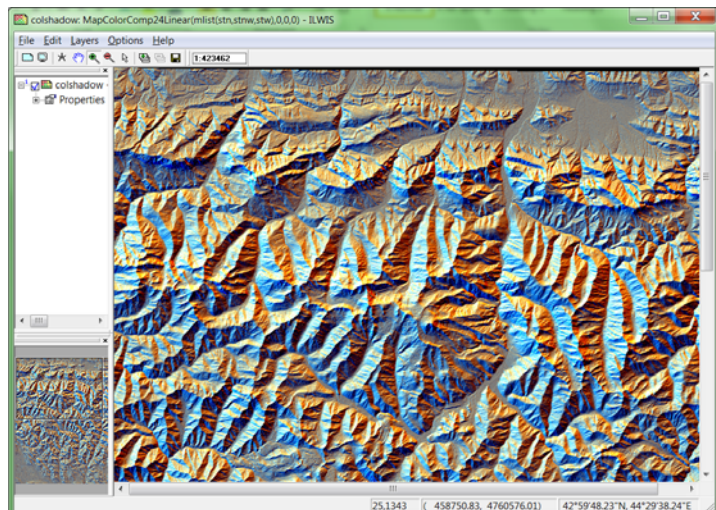
Creation of a subset of GDEM (Kazbegi area)

Resampling of the GDEM data to the already created GeoReference of the Kazbegi area with pixels of 30 m.

Detailed instructions:

- Select in the *ILWIS Main* menu: *Operations / Image processing / Resample.*
- Select or type in the *Resample Map* window:
    - *Raster Map:* select the downloaded SRTM file
    - *Resampling Method*: **Bicubic**
- Type the name of the **Output Raster Map**
- *GeoReference:* **Kazbegi_30m.**
- If done: **OK**
- Display the newly created GDEM. Check the Properties**.**

Checking the GDEM elevation values with the topographic contour line data scale 1:50.000

Detailed Instructions:

- Display the rectified GDEM
- Select in the *Display* window: *Layers, Add Layers, Kazbegi_contours*
- Select in the *Display Options – Segment Map* window : *line width* : **3** and an appropriate *Representation*
- Zoom-in to individual contour lines and check with the mouse-curser the elevations and the positions of the lines relative to the GDEM of the area with the contour lines.

Question: What are your conclusions about the accuracy?

....

It will be may be better to make a new Digital Elevation Model from the Kazbegi contour lines by interpolation and checking again this with the GDEM data.

Detailed Instructions:

- Select in the *Main ILWIS* window: *Operations, Interpolation, Contour Interpolation*
- Select in the *Contour Interpolation* window:
    - *Contour map* : **Kazbegi_contours**
    - *Output Raster map* : **Kazbegi_ContourDEM**
    - *Georeference* : **Kazbegi** (the one you created before)
  Suggestion: You can also use the given Georeference **Kasbegi_30m.**
    - *Domain:* **Value**
    - *Precision* : **1.0**
  Select: **Show**
- Open in the *Main ILWIS* window: **Pixel Information**
- Select in the *Pixel Information* window: *File, Add Map*
    - Add the GDEM in UTM WGS84 and the **Kazbegi_ContourDEM**
- Browse through the DEM with your cursor and compare the elevation values of both DEMs.

Question: What are your conclusions about the accuracy? Where are the elevation differences between both of the DEMs the highest?

....

....

Another way of comparing both DEMs is to make a new elevation model of only the differences between the contour DEM and the Aster GDEM.

Detailed Instructions:

- Type on the command line of the *ILWIS Main* window:
    DEMDIFF:= Name of AsterGDEM – Kazbegi_DEM

Check the result and draw conclusions. You will see that the differences are at places very high. What can be the reason of this?

2.5.4   Topographical attribute maps of the GDEM data

A slope map can be created from the DEM with the following steps:

- First one has to calculate from the DEM the height differences in X and Y directions. For this a linear filter can be used. The filter names are **dfdx** and **dfdy**. Name the output maps **DX** and **DY**.

- Instructions:
    - Select in the *ILWIS Main* menu: *Operations, Image Processing, Filter*
    - Select *Filter Type*: **Linear** and as *Filter Name*: **DFDX**
    - Type as *Output Raster Map*: **DX**
- Do the same Linear filtering of the Y direction

To calculate a **slope map** in percentages from these maps DX and DY on has to use a Map Calculation formula.

- Type on the *Command line* of the *ILWIS Main* window:
                 SLOPEPCT = 100 * HYP(DX,DY)/ PIXSIZE(DEM)
  Explanation: HYP is an internal Map Calculation function. Function PIXSIZE returns the pixel size of a raster map;
- For DEM, fill out the name of your DEM created before. **SLOPEPCT** is the name of the output map
- To convert the percentage values into degrees, type in the *Command line*:
                 SLOPEDEG = RADDEG(ATAN(SLOPEPCT/100))
  Function **ATAN** and B are internal MapCalculation functions. **SLOPEDEG** is the output map name of the slope map in degrees.

- To calculate an **aspect** map in radians and degrees from the maps DX and DY follow the instructions:
- Type on the *Command line* of the *ILWIS Main* window:
                 ASPECTR = ATAN2(DX,DY) + PI
- To convert the radians into degrees, type in the *Command line*:
                 ASPECTD = RADDEG((ASPECTR))

2.5.5 Stereopair of the Landsat TM Band-5 draped over GDEM.

The Stereo pair from DTM operation in the ILWIS program creates a stereo pair from a single raster image and a Digital Terrain Model (DTM). The (satellite) image will be displayed over the terrain.

The stereo pair can be viewed on the computer screen (split screen mode) with a stereoscope (screen-scope). or as an anaglyph using red-green or red-blue glasses**.**

Use of screen-scope

anaglyph glasses

In short, the process is as follows: First import the (satellite) image in ILWIS, including a geo-reference. Also import the DTM / DEM, which must have the same geo-reference as the image. The DTM can be created from (digitized) contour lines by interpolation. It is also possible to use an existing DEM, such as an Shuttle Radar Topography Mission Data (SRTM)DEM, ASTER GDEM or other DEM

Remark: The best quality you will get if the image and the DTM have approximately the same spatial resolution.

In ILWIS we use the "Stereo Pair from DTM" option for the operations. Rotation differences and possible scale differences between the image and the DTM / DEM will be removed.

Stereoscopy: seeing of objects in three dimensions

Detailed instructions:

- Select in the *ILWIS Main* window: *Operations, Image Processing, Stereo Pair from DTM*

- Select in the *Stereopair from DTM* window the Raster Map and the DTM. Use for both the subsets of the Kazbegi area. Select: **Show** to display the Stereo Image.

- Now, both the DTM and the image will be re-sampled to Output maps, i.e. the stereo pair is calculated. Rotation differences and possible scale differences will be removed and the stereo--pair will appear on the screen.

- To show the stereo pair a next time on the computer screen, *right mouse-click* the stereo pair icon in the *Catalog*: . After this select: *visualization, with Stereoscope*

- To create an Anaglyph image you have to repeat Step 3 by selecting: V*isualization, as Anaglyph..,*

Stereo viewing - Tips and hints

- To properly view the stereo pair, you have to resize the Stereoscope window so that the horizontal distance between the left-hand and the right-hand photograph fits your eye base.
- Make sure that the splitter between the left-hand pane and the right-hand pane in the Stereoscope window is in the middle of your stereoscope.
- Make the Stereoscope window larger /smaller, by dragging a corner of the window.
- When you use Zooming, Panning, Entire map or Redraw or when you scroll in one of the displayed photographs, this will be applied to both panes.
- To move one or both photographs a little to the left or to the right, in order to improve stereo vision, you may unlock the left pane and right pane from each other.

2.6 SEARCHING THE EUROPEAN CLIMATE ASSESSMENT DATASETS

The objective of ECA&D is to combine collation of daily series of observations at meteorological stations, quality control, analysis of extremes and dissemination of both the daily data and the analysis results. Integration of these activities in one project proves to be essential for success. New versions of the daily dataset will be issued at regular intervals. The ECA dataset consists of daily station series obtained from climatological divisions of National Meteorological and Hydrological Services and station series maintained by observatories and research centres throughout Europe and the Mediterranean.

	Websites for download	Description
ECA&D	http://www.ecad.eu/	http://www.ecad.eu/FAQ/index.php#0

2.6.1 Searching Data

The data is released on a monthly basis. The datafiles contain gridded data for 5 elements (daily mean temperature TG, daily minimum temperature TN, daily maximum temperature TX, daily precipitation sum RR and daily averaged sea level pressure PP). the data can be downloaded based on a regular and rotated grid.

Detailed instructions:
- Browse to the **ECA&D** website: ***http://www.ecad.eu/***
- **Register first** and fill in your personal data. After this you will get two emails. The first mail is for confirmation and the second mail includes a link to download the data. Keep this mail as a reference.
- After **Login** select the link to : *Visualize Daily Maps*.
- First Select an element, such as **Mean temperature** or **Precipitation amount**
- Select: **Year, Month and Day**
- Zoom-in to certain areas
- Repeat for other Climate elements or dates
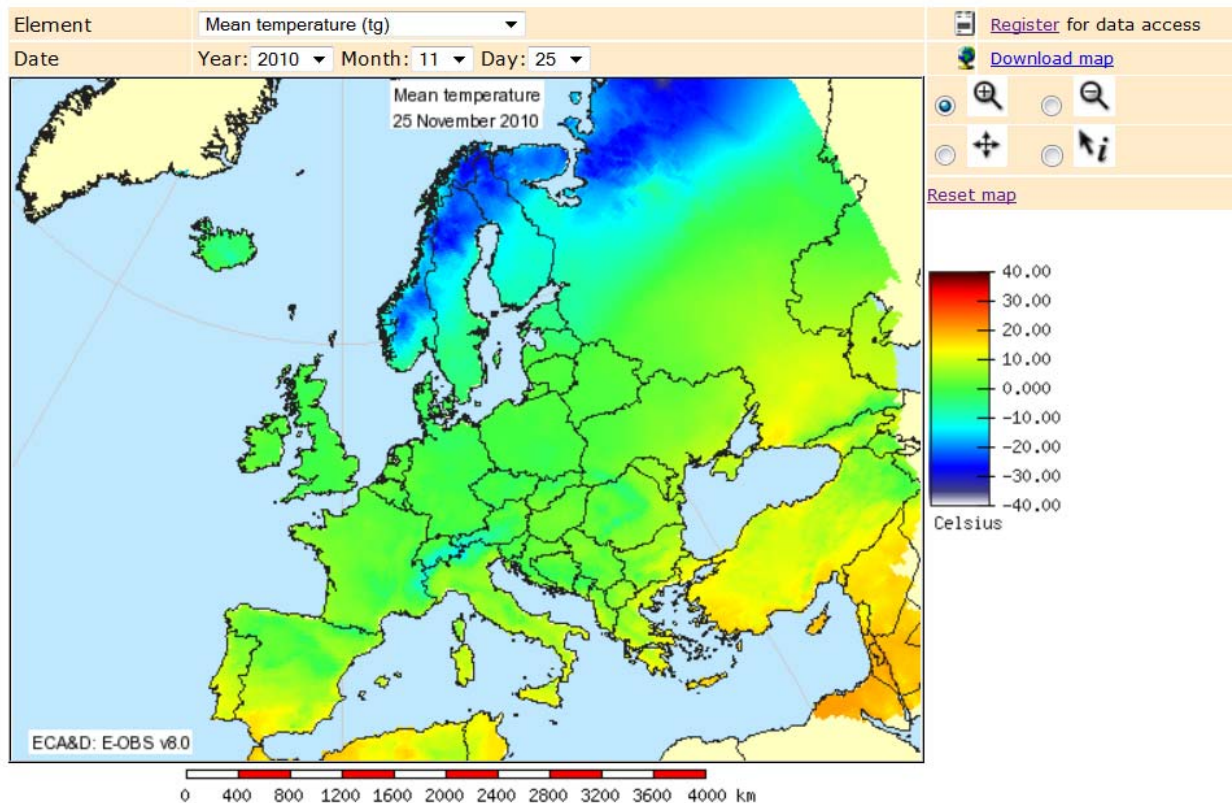
2.6.2   Searching indices of extremes and extreme events

Data of extremes and extreme events can also be browsed at the ECA& D website. This is of course highly relevant for disaster studies. One can browse among others maps of trends over Europe for each index, time series plots / trends and anomalies (with respect to the normal period 1960 – 1990). All data are updated until 2012. Every item of the menu offers the option to download the results.

Further information on the various indices is given by ⓘ

Detailed instructions on **indices of extremes**:

- Select **Indices of Extremes**
- Select: **Trend Maps**
- Select a **Category, Index, Period** and **Season** for which you want trends to be displayed.
- Zoom-in to certain areas
- Repeat for other Categories, Indices and/or Periods.
- Select ⮕ᵢ and after this click a **Meteo station** ◉ to see the trend details.
- Download the Mapview if you like. This is only in PNG file format and without coordinates.
- Download the data, UNZIP and open in MS Word to see the data per station with Lat /Long coordinates.

Extreme weather and climate events have significant impacts and are among the most serious challenges to society in coping with a changing climate. According to the latest IPCC report, "confidence has increased that some extremes will become more frequent, more widespread and/or more intense during the 21st century".

The menu allows you to select descriptions of some of the recent extreme events. Each event is placed in the context of climate change.

Detailed instructions on **extreme events**:

- Select **Extreme events**
- Select: **Query event catalogue**
- Select a **Event Name, Geo theme, Category, Year** and **Country**.
- Download the resulting map as a PDF
- Repeat for other Extreme events of your choice.

3 GENERATING AND ANALYZING HISTORICAL DISASTER DATABASES

Expected time: 2 hours
Data: **Exercise_historical_events.zip**
Objectives: After this exercise you will be able to:

- Analyze different sources for historical information on disaster events
- Understand the importance of collecting complete data on past events.
- Analyzing databases of past events.

3.1   INTRODUCTION

This exercise presents a crucial component for the generation of national scale hazard and risk maps: the collection of historical data for the different types of natural hazards that are occurring on the territory of Georgia.

Historical data is crucial, as it is needed for:

- Generating the hazard maps. Many of the methods for hazard assessment are based on analysis of conditions that have let to hazardous events in the past, and use these combinations to indicate where these events may happen in the future. For this we would need historical data with an **accurate location** of the past hazard events. Preferably in the form of hazard pplygons, that indicate where in the past events such as flooding, landslides, snow avalanches, or earthquakes have taken place. These data should ideally also contain **intensity information** (e.g. water height, earthquake intensity).
- Validating the hazard maps. Even if we cannot use historical damage data to generate the hazard maps, we need past information to vaslidate whether our susceptibility or hazard maps are correct. Most of the past events should have occurred in the high hazard zones. Provided that the factors that determine the hazard have not changed over time.
- Establishing frequency of events. For this we need a historical database that is **as complete as possible**, in order to estimate or calculate the frequency of occurrence of hazardous events in the different parts of the area. So we need **accurate date information** for the past events.
- Generating vulnerability and risk maps. We need attribute information on the **damage caused by past events**, such as number of buildings destroyed, casualties, crops affected etc. in order to be able to estimate the level of future risk and to evaluate whether our risk maps portray the right order of magnitude.

Collecting past damage information is one of the most complicated issues in national scale hazard and risk projects, and often not enough attention is paid to this component.

For the case study of Georgia, we have generated a database that contains information on the following types of hazard: earthquakes, landslides, mudflows, rockfalls, floods, snow avalanches, drought, hailstorms windstorms and wildfires. The database generation was a complicated procedure. Most of these data have been collected by teams from National Organizations. For instance, the earthquake data has been provided by the Institute of Earth

Science of the Ilia State University, and most of the data on hydro-meteorological hazards have been collected by the National Environmental Agency. Unfortunately not all the natural hazards have been covered in the database and the Atlas, specifically soil erosion, soil contamination and coastal hazards. Also technological hazards have not been taken into account. And the data on the hazard types that were taken into account is very incomplete. This is caused partially by the fact that in Georgia, after independence, most of the hazard monitoring infrastructure has collapsed. The number of active meteorological stations and river gauging stations reduced dramatically due to lack of funds. And data on the occurrence of evens like landslides, snow avalanches, droughts etc was lost as they were originally in paper reports in Russian language, which due to reorganizations of government organisations

and due to internal political problems, were lost. A lot of data from the archives from the National Environmental Agency on hydrogeological events was lost because the building of NEA was used for housing refuges during conflict periods, and the paper archives were used to heat fires for cooking by the refuges. Part of the archives of NEA were thown into one room. In the framework of the project a group of people tried to rescue the information from these archives and digitize the information into a database.

3.2   USING INTERNATIONAL DATABASES

At an international scale there are a number of data sources for disaster related information, which might be of use when making a nationals scale disaster database.

The most cited one is the EM-DAT database, maintained by the Centre for Research on the Epidemology of Disasters (CRED) of the University of Leuven (Belgium) with support from UN organizations. Data from this database are often quoted as the official disaster statistics in international publications. However, this database has a number of problems:
- It uses certain criteria to decide whether disaster events should be included:
    o Ten (10) or more people reported killed.
    o Hundred (100) or more people reported affected.
    o Declaration of a state of emergency.
    o Call for international assistance.
   This makes that many (most) of the smaller disaster events are not recorded in this database.
- Many of the side effects of major disasters (e.g. landslides caused by an earthquake) are grouped under the main disaster. Therefore the database contains a large underestimation of some of the hazard types.

- Evaluate the disaster database from EM-DAT for the country of Georgia. Go to the website: http://www.emdat.be/database
- Select Advanced Search, and make a search for a particular type of disasters within the country of interest. Make a summary of the results, and compare your own knowledge on the events that have happened. How complete is this database?
- You can also check additional disaster data resources at: http://www.emdat.be/additional-disaster-data-resources
- We have also an older version (up to the year 2000) of the EMDAT database available as Excell file. Check out the file **EMDAT_old** using Excel and find out the disasters recorded for Georgia or for your own country.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	DisNo	Country	IsoCode	Region	Continent	DisGroup	DisType	Year	Month	Day	Killed	Injured	Homeless	Affected	TotAff	DamageUS ('000s)	PrimarySourc
2581	19910117	Georgia	GEO	Russian Federation	Asia	Natural	Earthquake	1991	4	29	270	1500	160000	90000	251500	1700000	UN-OCHA
2582	19910122	Georgia	GEO	Russian Federation	Asia	Natural	Earthquake	1991	6	15	8	200	?	15000	15200	?	UN-OCHA
2583	19920481	Georgia	GEO	Russian Federation	Asia	Natural	Earthquake	1992	10	24	0	?	?	?	?	?	UN-OCHA
2584	19950173	Georgia	GEO	Russian Federation	Asia	Natural	Flood	1995	7	0	1	?	?	300	300	?	UN-OCHA
2585	19970117	Georgia	GEO	Russian Federation	Asia	Natural	Flood	1997	5	23	0	?	200	?	200	?	Lloyds Cas Wl

The best databases are developed by the Reinsurance companies, but are not publicly accessible. For example:

- MunichRe NATHAN: http://www.munichre.com/de/reinsurance/business/non-life/georisks/nathan/default.aspx
- SwissRe Sigma. Although you can't access the database they have anice visualization tool: http://www.sigma-explorer.com/

There are also several other international databases. The Global Risk Information Platform (GRIP) has made an effort to combine digital available disaster databases on the web in one portal.

- Go to the web-site: http://www.gripweb.org/gripweb/?q=disaster-database
- Check whether it contains any data of your country of interest.

There are also other databases. One of them is DESINVENTAR, and another one is GLIDENUMBER

- Go to the web-site: http://www.desinventar.net/
- Check whether the DESINVENTAR database contains any data of your country of interest.
- Go to the web-site: http://www.glidenumber.net/
- Check whether the GLIDENUMBER database has disaster information of the country of your interest.
- Do you know of other online databases on disasters for your country of interest?
- What can you conclude about the availability of disaster information for your country?

There are also a number of data visualization tool for worldwide disaster data available.

- Go to the PREVIEW web-portal and check out the data for Georgia using the interactive viewer: http://preview.grid.unep.ch/
- You can also download worldwide data from this website (use the option Data_Extraction). Select the country: Georgia, and select one of the desired types of data. E.g. Risk. Click on the file name to download it. Extract the file from the ZIP file, and convert the TIF file to ILWIS. Change the properties of the Georeference, and change the coordinate system into LATLON. Overlay the ILWIS map Communities_ID (Boundaries Only) to get an idea of the very poor data resolution of these datasets.
- You can also check out the Risk data Viewer of the Global Assessment Report on Disaster risk Reduction 2013 at: http://risk.preventionweb.net

3.3   WEB-BASED DISASTER INFORMATION FOR GEORGIA

Regular collection, updating and analysis of information on natural disasters plays an important role in the activities of government institutions and expert organizations associated with the management of natural disasters or/and mitigation of their negative impacts. The generation of a detailed database is a complicated and long term process, which includes not only recording of past natural disasters but also standardization, re-checking and regular updating of the existing data. Timely provision of these data to the population and relevant agencies is very important for the management of disasters, in each step of the disaster cycle.

To collect the data for Georgia, also reported historical (non-instrumental) records have been collected from various departments of the National Environmental Agency, the Forest Management Department, and various other archives, as well as from mass media programs (Rustavi-2, newspapers and journals), monographs and scientific publications with regard to the following natural disasters: floods, flashfloods, mudflows, landslides, rockfalls, hailstorms, windstorms and wildfires. When combining the obtained information and putting together the database, the importance of introducing a unified recording structure for each natural event has become obvious. To do this it has become necessary to convert all the past events recorded by various organizations into a unified format first and then apply the unified information framework to it. This will make it possible to update, specify and extend the database with minimum loss of time and resources in future.

Along with the collection, systematization and updating of the database, it is also extremely important to timely provide and exchange the information with various central and local governments as well as the population to enable them to take respective actions and ensure readiness and timely response to natural events and reduce the consequences. This objective (risk communication) is an important reason for creating a web-based risk atlas. Application of internet technologies provides the possibility not only to make the database available for the public at large, raise the awareness of the population, local authorities and improve their

preparedness for dangerous/hazardous events, but also improve the existing database and ensure regular updating. Any user, through the respective functions, can contribute to disaster risk reduction and provide additional information to the web-site administration about occurred natural events, which, after being specified and rechecked, will be used for updating the database. The Figure above shows the web-site function where a user can indicate the location, date, occurred damage/loss, photo/video and other significant supplementary information on a certain natural hazardous event.

- Go to the web-site: http://drm.cenn.org/
- Select the option: Disaster Reporting. Select the Option: **Input**. Practice with the tool to report a disaster event using the web-based interface.

Besides, the web-atlas provides the possibility to query information on natural disasters by types and dates on various administrative levels (regional, municipal, and community). The Figure below shows for example the number of recorded landslides by municipalities, which is presented by gradation of colors. During the search, an interval between the years of 1995-2011 can be selected.
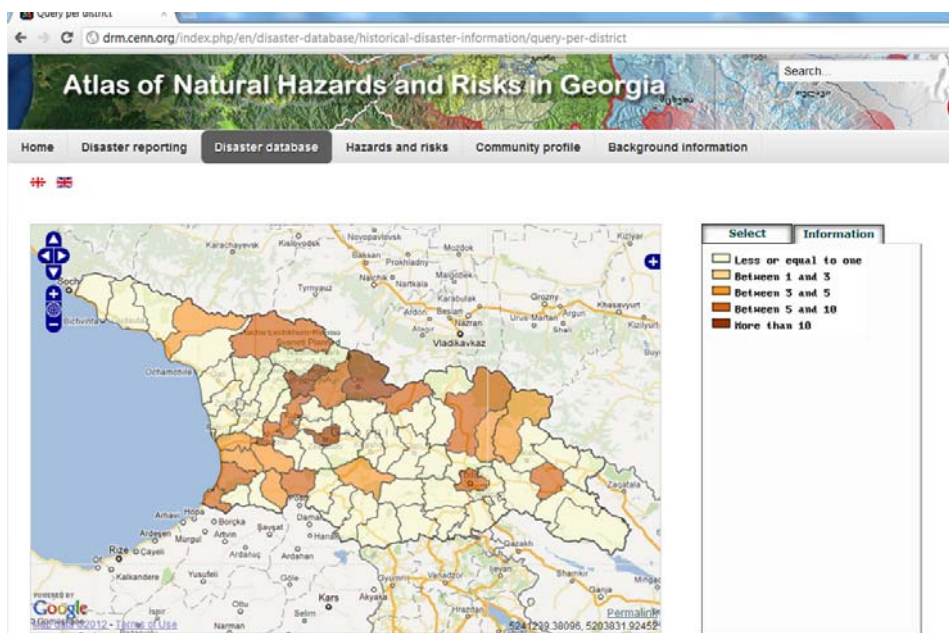
Figure. 3.2. The Web-Atlas function for searching historical Natural Disaster events

- Go to the web-site: http://drm.cenn.org/
- Select the option: Disaster Database. Practice with the tool to query individual disasters as points, or aggregated information per administrative unit.

Due to poor accuracy, sometimes even absence of the data, it has become impossible within the framework of the Project to query other information (on past damages, human losses, etc).

3.4   ANALYZING THE GENERAL DISASTER DATABASES IN A GIS

We have also a number of disaster databases for Georgia in a GIS form. In the following sections we will show you how they are designed and how you can use them to get information about the location, frequency, and damage caused by past events, and we will also show you the problems involved in using incomplete databases for further hazard and risk assessment.

For the exercise a number of input maps are available, for which the characteristics are given in the table below:

Map	Description
Past_events	A point map and large table with the historical events that have been collected for Georgia
Disaster_ID	A Table with information on damage caused by past disaster in Georgia. Each disaster has a unique ID.
Earthquakes	Earthquake database and point map, containing all historic and instrumented earthquakes in Georgia.
Landslides	Point map with locations of known landslide events, with some attribute information in a table.
Mudflows	Point map with locations of known mudflow events, with some attribute information in a table.
Rockfalls	Point map with locations of known rockfall events, with some attribute information in a table.
Snow_avlanches	Polygon map with locations of known rockfall events, with some attribute information in a table.
Community_ID	Polygon map of the adminstrative units in Georgia, whcih we will use to aggregatet he disdaster5 statistics.
Show_hazard	Script file that will be used to display the number of disaster events for a particular hazard type within a certain time period per administrative unit.

We start by having a look at the point map of the historic disaster events and the associated data in the attribute table. All data are in ILWIS format.
Instructions:

- Open the polygon map **Community_ID**. In the *Display Options* Window select the option: *Boundaries Only*. The map displays the administrative units in Georgia, with the communities as the lowest level subdivision.
- Select *Layers, Add Layers*, and add the *point map* **Past_events**. Select *Single Symbol* with **Red** fill and line colour
- In the *ILWIS Main* window select: *PixelInfo (the **i** button)*, and add the *Polygon map* **Community_ID** and *Point map* **Past_events**. Select: *Options, Always on Top*.
- Zoom in and make an evaluation of the contents of the map.
- Right-click and select in the *Display Option* Window of the map **Past_events**: *Attribute*. Select the *C*olumn **Hazard_Type.** Now the past events are displayed according to their hazard type.
- Try also to display some of the other attributes.
- Formulate the main limitations of the database that you have seen thus far.......

What is clear from analyzing the map in detail is that there are often only points in the middle of the community, and that many of the disaster events have a point in the same location, which doesn't make it possible to visualize, and consult, all of them in the map. This means that the exact location of the disaster event is not known, as the original data source only mentions the locality (community) where the event took place, without a map. This means that most of the disaster events are not located where they actually occurred, which makes it impossible to use them directly in a hazard assessment that is based on a statistical analysis

(which correlates past event locations with the factors at these locations, such as slope angle, landuse, geology etc.). The only exception are the earthquake epicenters, which are distributed throughout the map, and also outside of the country. Furthermore, since most of the events are displayed as points in the center of the community, you do not see all of them as they are displayed on top of each other. We will also analyze the contents of the table in more detail.

- Open the table **Past_Events**.
- Scroll down to check the total number of records is the database. This is ....

For each of the records the type of hazard is indicated. We can calculate the total number of records per hazard type in the following way:

- Select in the table **Past_events** : *Columns, Aggregation*. In the *Aggregate Column* window, select *Column*: **Hazard_Type**, *Function*: **Count**, *Group By*: **Hazard_Type. Type for** *Output Table*: **Hazard_Type** and for the *Output Column*: **Number_records**
- Open the new table **Hazard_Type** to check the results.
- Select the **Graph button** (📈) and select *X-Axis*: **Hazard_Type**, and *Y-axis*: **Number_records** and after this: **OK**. You can adjust the axes and fonts and graphtype in the graph window. You can also save the graph.

Hazard Type versus the Number_Records

- Which hazard type contains most records? Is this logical? What do the numbers say about the completeness of the database?
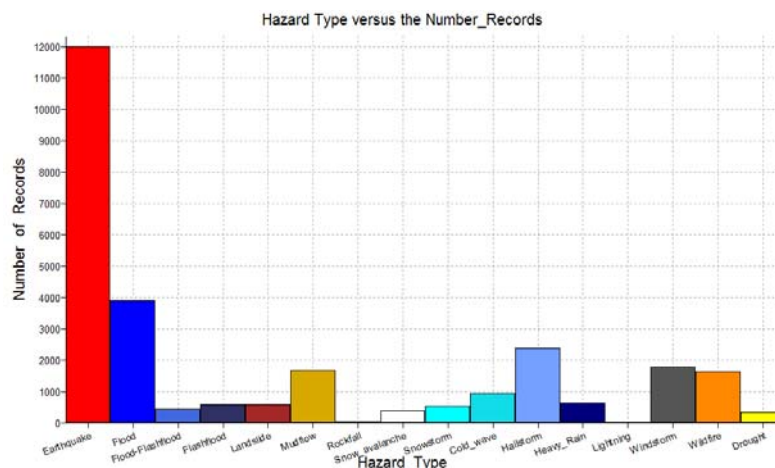
We can also check the time covered by the disaster events.

- In the table **Past_events**, Select *Columns, Aggregation...* In the *Aggregate Column* window, select *Column*: **Year_s**, *Function*: **Count**, *Group By*: **Year_s.** Type for *Output Table*: **Year**, and for *Output Column*: **Number_records**
- Open the new table **Year**. You can see the number of records per year. Let us also calculate the cumulative. Select *Columns, Cumulative* and in the *Cumulative Column* window : Column: **Number_records.** Type for *Output Column*: **Cum_records** and after this press **OK.**
- Select the graph button (📈) and select *X-Axis*: **Year**, and *Y-axis*: **Cum_records**. You can adjust the axes and fonts and graphtype in the graph window. You can also save the graph.
- What can you conclude with respect to the temporal coverage in the database?

When you look closer in the table **Past_events** you can see that the table contains a number of repetitive events, e.g. the same hazard type that occurred on the same day, but in different communities (you can see that they have different values for the column **Community_ID** which links to the location of the community where the event took place).

In the construction of the database this is a major problem, as it is the question whether these multiple events that occurred simulateneously in different locations, should be seen as a single or as multiple events. Especially when recording the damage information. That is why each separate disaster event was given a unique identifier (**Disaster_ID**).

The table **Past_events** also contains information on the source of the data (Column **Information_Source**) and on the person that entered the data in the database (**Person_Entry**).

- In the table **Past_events**, Select *Columns, Sort...* In the *Sort* window, select *Column*: **Information_source**, *Descending* and after this **OK**. Now the table is sorted according to the information in that column. Check the different information sources that were used for making the database. What is the information source for the earthquake information?

To check the difference between the number of events recorded in the table **Past_events** and the unique disaster events, stored in the table **Disaster_ID**, we will now look at this other table.

- Open the table **Disaster_ID** and find out how many individual disaster events are recorded in the database. What is the difference with the number of events stored in the Table **Past_events**? How can you explain the difference? What is the link between the two table? Is it possible to display the disaster _ID in a map?

As you can see that this table contains information on the damage caused by the disaster events. As the information on damage is very scarce, these columns are very incomplete, and it will be probably difficult to decide based on its contents whether a certain disaster event had any damage or not, or whether the damage reported is correct. You can use the same tools to analyze the damage due to the various types of hazards.

- Select in the table **Disaster_ID** : *Columns, Aggregation….* In the *Aggregate Column* window, select *Column*: **Damage_economy**, *Function*: **Sum**, *Group By*: **Hazard_Type**, Type for *Output Table*: **Hazard_Type** and for *Output Column*: **Damage_economy.** After this select **OK.**
- Do the same for a number of the other damage columns, so that you get a summary of the damage information per hazard type.
- Open the new table **Hazard_Type** and display the damage information in graphs. Prioritize the hazard types according to the results, and put he results in the table. Are these results logical?

Damage	Highest hazard type	Damage	Highest hazard type
Economic damage		Crops	
Population		Forest	
Buildings		Animals	
Roads			

We can safely conclude here that the database of historical disaster events for Georgia is far from complete. Both in terms of temporal coverage , spatial representation, consistency and attribute information there are many problems that make it difficult to use the database directly in a quantitative analysis. Therefore it has been used more as a learning tool, and

the various steps in the subsequent hazard and risk assessment were made using expert opinion.

3.5 AGGREGATE THE RESULTS PER ADMINISTTRATIVE UNIT

We can also use the disaster database to aggregate the data to an administrative unit level. We would like to be able to display per community, district or region how many events were recorded for each of the hazard types. This part shows the steps how to do that. We will eventually create a number of columns on the table **Community_ID** which is linked to the **Community_ID** map.

- Open the table **Past_Events**. Create separate columns for the types of hazards you are interested in, using the following style of equations. We will do it now only for Floods:
  Flood:=iff(Hazard_Type="Flood",1,0)
- In the table **Past_Events**, select *Columns, Aggregation….,* Select the column: **Flood**, Function: **Sum**, *Group_By*: **Community_ID.** Type for *Output table*: **Community_ID** and *Output Column*: **Flood**.
- Open the Table **Community_ID** and check the values of the newly created column **Flood**.
- Display the map **Community_ID** , select the option *Attribute* and select the column **Flood**. Now the number of flood events is shown per community. You can adjust the upper level of stretching (making it lower) to get a better representation of the colours.
- You can practice a bit more with that for other hazard types.

With a few simple lines of commands in a so-called script file, you can automate the calculation steps, and it is also possible to develop your own queries. For example, we have made a small script called **Show_hazard** that allows you to select a hazard type and a time range between two years. The script then calculates how many events have taken place in that time period.

- Open the script file **Show_Hazard**.

As you can see the script uses 3 parameters:
- %1 = the name of the Hazard Type. This should be the exact name as is written in the column **Hazard_Type** in the table **Past_events**. You can also open the domain **Hazard_Type** to check the names
- %2 = the starting year of the period for which you want to display the results
- %3 = the ending year of the period for which you want to display the results

- Close the script file Show_Hazard. Type on the *Command line* of the ILWIS Main menu:
  Run Show_Hazard Flood 1900 2013
  (So the three parameters follow the name of the script.) After some seconds the calculation is completed and the result map is opened.
- Use the scrip to make other queries as well.
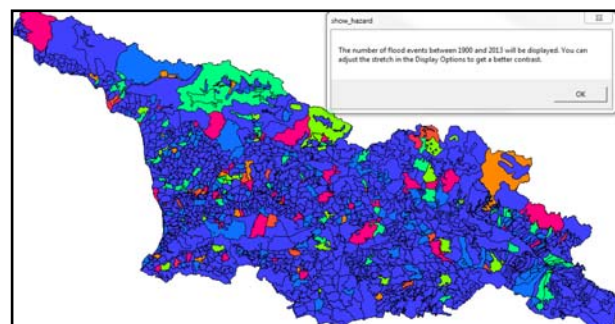
3.6   ANALYZING EARTHQUAKE DATA

The earthquake data in the table **Past_events** contains a large number of earthquake events, which have not resulted in disasters, as the magnitude was very small. To get more information on earthquakes, there is also a separate earthquake map and table.

- Open the point map **Earthquakes**. In the *Display Option* – Point Map window, select *Attribute*, and select the column **Magnitude**. Select *Symbol*, select *Red color*, and select the option *Stretch*. Use the values: **3.5** to **7.00** (Magnitude), and **2** and **25** (Size of circles). Click *OK, OK*. The earthquakes are now displayed as circles. The bigger the circle the larger the magnitude.
- Add the Polygon map **Community_ID**, *Boundaries Only*, so that you can see the various parts of the country.

As you can see most of the earthquakes have low magnitude and would not cause major damage. There are also clear clusters of earthquakes which are related to the major faultzones in the country. We can also display the earthquakes according to both depth and magnitude.

- Right click in the map, and select the *Display Options* for the map **Earthquakes**. Deselect *Attribute*, and select *Symbols by Attributes*. Select *Details….*. Class: **EQ_Depth**, Select *Stretch*, *Column* **Magnitude**, and stretch from 2 to 20. Click *OK*. Shallow earthquakes are shown in red, and deep earthquakes in blue. It is clear that the largest earthquakes with M=7 also were rather shallow.

- Open the *PixelInfo* window so that you can check all earthquake attributes
- Close the map window and open the table **Earthquakes**. We will calculate the number of earthquakes per magnitude class, which is the basis for analyzing earthquake frequency. Select *Columns, Aggregation…, Column*: **Mag_Class**, *Function*: **Count**, *Group by*: **Mag_Class.** Type for *Output table*: **Mag_Class** and *Output Column*: **Number**.
- Open the table **Mag_Class.** To calculate the cumulative number of events select *Columns*, *Cumulative*, select the column: **Number**, *Output column*: **Cum_Number,** and *OK,OK*.
- We can now calculate how many events are larger than a certain magnitude class. The total number of events in 4001. In the command line type:

<p align="center">Larger_than:=4001-cum_number</p>
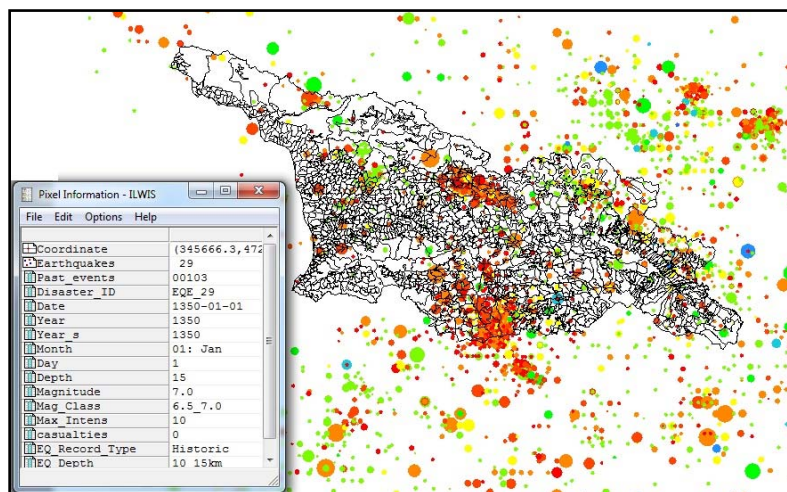
- Make a graph plotting **Mag_Class** as X-Axis, and **Larger_than** as Y-Axis (logarithmic axis, which you can change by double clicking on the left side on the Y-Axis Left).

You see now that there is a straight line, which represent the Gutenberg-Richter relationship for earthquakes ($\log_{10} N = a - bM$). We can therefore see that Earthquake records are suitable for hazard assessment, as they are recorded by a seismic network. Characteristics of large earthquakes before the existence of seismic networks, are obtained from archives and using field evidences. See also the column EQ_record_Type in the table Earthquakes.
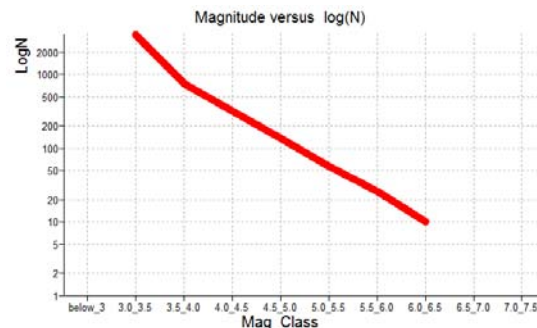
- When was the first seismic network installed in Georgia?

3.7   ANALYZING MASS MOVEMENT DATA

Finally we also would like to show a number of other databases, for landslides, mudflows, rockfalls and snow avalanches. The first three are only point files, whereas the snow avalanche map shows the actual extend of the events as polygons. The latter is much better as we can use that for analyzing the relation with causal factors. We will first compare the location of the points from the landslides, mudflows and rockfall files with those of the general database (**Past_Events**).

- Open the table **Past_Events**. We will now only select the events with landslides, mudflows and rockfall, using the following equation:

MassMovement:=iff((Hazard_Type="Landslide")or(Hazard_Type="mudflow")or(Hazard_Type="Rockfall"),Hazard_Type,"None")

- Close the table. Display first the map **Community_ID** with *Boundaries Only*. Then select *Layers*, *Add layer…*: **Past_Events**, Select *Attribute* and select the Column: **MassMovement**. Representation: *Hazard_Type* and after this *OK*.

We made sure that all other events are displayed as white and only the mass movement events are shown. You see that most of the points are only in the center of the community, as there was not enough information at that time to located the landslides exactly. And unfortunately for most of the landslide, mudflow and rockfall events we do not the time of occurrence, so it is difficult to match the two datasets.

- Select *Layers, Add layer…,* select the point map **Landslides**. Use single Symbol, and display it as red circles. Zoom in on some of the areas to verify that the points of the **Past_Events** do now match with the exact locations of the landslides in the point file **Landslides**.
- You can check the same for the mudflows and rockfalls.

We can also see that there are quite some communities where the **Past_events** database doesn't show landslides, where the point file **Landslides** does have quite a few. This is a difficult problem to deal with when constructing the past events databases.

- Finally also add as a layer the polygon map **Snow_Avalanches**. As you can see this is not a point map but contains the actual affected areas by snow avalanches.

The snow avalanche data is actually the best, in spatial terms. It shows where there were large and smaller snow avalanches, and we can relate the location of the snow avalanches directly with important factors such as slope steepness, forest cover, slope direction, altitude etc. that are needed for making a snow avalanche hazard map. Unfortuantely all the individual point maps of landslides, mudflows, rockfall and snow avalanche lack information on date of occurrence and damage. The only thing we can estimate is the area affected.

- Open the table **Snow avalanches**, and check the number of events recorded, and the average size of the events (Using the statistics pane at the bottom). Later in the exercise on risk assessment we will use this type of information to estimate the number of events that are possible in future, and their average size.

Ideally all the hazardous events should be mapped as polygons, instead of points, or at least as points localized with proper X and Y coordinates, and should have date and damage information. If this is not the case the data is not.

3.8   SOME ADDITIONAL QUESTIONS

If you would like to try out some analysis on the past events databases yourself, without detailed instructions, here a number of possible questions that can be answered using the data:

- Which months of the year are most problematic in terms of floods and landslides?
- In which months do most of the snow avalanches occur?
- How many of the disasters have occurred at community level, district level or regional level?
- Display the number of earthquakes with a magnitude more than 5.
- Which of the communities has the highest number of historical hydrometeorological disasters events?
- How many earthquakes and of which magnitude have occurred within a distance of 150 kilometers from the Capital of Tblisi. What was the maximum intensity?
- What is the average size of landslides, mudflows and rockfalls?

Due to the incompleteness of the databases, we cannot get quantitative answers to a number of fundamental questions required for the risk analysis, such as:

- What was the damage (economic, population, buildings etc.) of different types of disasters in the past decades, for different administrative units?
- What was the intensity of the past hazards, and can we make an intensity-frequency relationship to know the probability of hazard events in future?
- Where did the past events occur exactly so that we can use them in generating hazard maps?

Since we cannot answer these fundamental questions quantitatively, due to the incompleteness of the database, we have to apply (semi)qualitative methods for the hazard and risk assessment.

4 QUALITATIVE LANDSLIDE HAZARD ASSESSMENT USING SPATIAL MULTI CRITERIA EVALUATION

Expected time: 2 hours
Data: **Exercise_landslides_SMCE.zip**
Objectives: After this exercise you will be able to generate:
- A hazard index, which combines a number of factors for the country of Georgia, and generate a composite index map showing the ranking of these hazards.
- All procedures are based on Spatial Multi Criteria Evaluation

4.1   INTRODUCTION

For this exercise we use data which has been generated in the framework of the MATRA project explained above. All data is in raster format, and the raster maps have a pixelsize of 100 by 100 meters, so representing 1 hectare. Although the actual method used is more complicated we will show a simplified version of it, giving the time available for this exercise. We will use the most important types of factors that are used in national scale landslide susceptibility assessment. Several methods can be used for landslide susceptibility and hazard assessment, depending on the availability of data, the size of the study area, the homogeneity of the area, and the objectives of the study. In this example we will use a qualitative method, called spatial multi-criteria evaluation, which qualitatively combines a number of factor maps into a susceptibility index map, whcih is classified into three susceptbility classes. given the incompleteness of historical landslide inventories, this is the most suitable method at this scale.

4.1.1   **Landslide Hazard input data**

For the hazard assessment a number of factor maps are available, for which the characteristics are given in the table below:

Map	Description
Slope	a slope map of the study area with slopes indicated in degrees, derived from a digital elevation model (DEM).
Geology	a geological map and tables of the study area, derived from existing geological maps (scale: 1:500 000).
Fault	data derived from geological map as one of the factor for landslide occurrence.
Landuse	a landuse map of the study area (scale: 1:500 000)
Landslide	landslide distribution map of the area.
Georgia State	National border of Georgia

Note that in this analysis we do not consider the triggering factors: precipitation and earthquakes, which should also be included when carrying out a more complex analysis.

4.2   INTRODUCTION TO SPATIAL MULTI-CRITERIA EVALUATION

Spatial multi criteria evaluation is a technique that assists stakeholders in decision making with respect to a particular goal (in this case a qualitative risk assessment). It is an ideal tool for transparent group decision making, using spatial criteria, which are combined and weighted with respect to the overall goal. For implementing the analysis in the case study, the SMCE module of ILWIS was used. The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardized and weighted in a criteria tree. The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).
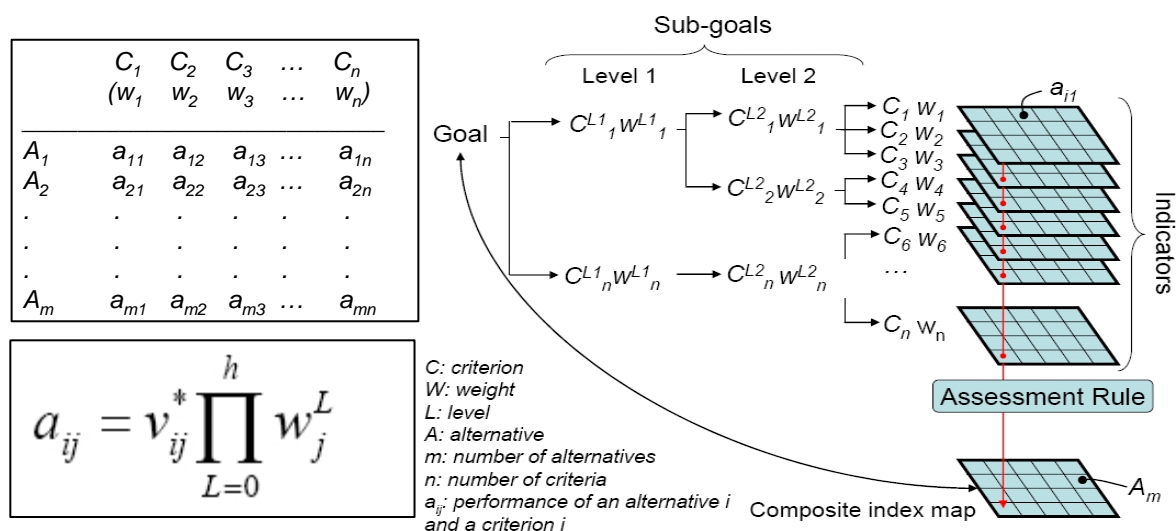
Figure . Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardised and weighted in a 'criteria tree.' The output is one or more 'composite index map(s),' which indicates the realisation of the model implemented.

From a decision-making perspective, multi-criteria evaluation can be expressed in a matrix as shown in the figure above. The matrix A contains the criteria in one axis (C1 to Cn), and a list of possible alternatives, from which a decision has to be taken on the other axis (A1 to Am). Each cell in the matrix (aij) indicates the performance of a particular alternative in terms of a particular criterion. The value of each cell in the matrix is composed of the multiplication of the standardised value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W1 to Wn) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a11 to a1n for alternative A1).

For implementing this matrix according to the AHP, three principles steps need to be considered. The first one decomposes the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the

hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (Cj) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative Aj. The goal (risk index) has been decomposed into criteria levels CL1 and CL2. The intermediate levels are often indicated as sub-goals or objectives (e.g. in level 1, the sub-goals are a 'hazard index' and a 'vulnerability index'). Each criterion of each level will also have an assigned weight. Therefore, the values for the layers of the intermediate levels are obtained through the summation of the performance for the alternative at lower levels. As the criteria consist of raster maps, their spatial performance (aij) and the alternative (Ai) will be identified for particular raster cells.

The composite risk index map is obtained by an assessment rule (sometimes also called decision rule), which is calculated by adding up the performance of all cell values of the different criteria (aij) for the particular alternative. However, the performance of every element in the matrix (aij), is obtained in a different way:

In this equation, vij refers to the standardised value of criterion (Cj) for alternative (Ai), and weight wLj refers to the weight of criterion (Cj) for level L (0–h levels). During the analysis, it could be desirable (and sometimes necessary for a better definition of the weights wLj) to produce the intermediate criteria maps.

General steps in the process are:
- Definition of the problem. Structuring of the problem into a criteria tree, with several branches or groups, and a number of factors and/or constraints.
- Standardization of the factors. All factors may be in different format (nominal, ordinal, interval etc.) and should be normalized to a range of 0-1. SMCE has some very handy tools for that especially for value data, making use of different transformation graphs.
- Weighting of the factors within one group. SMCE has some very handy tools for that derived from Analytical Hierarchical Processing (AHP), such as pair wise comparison and rank ordering.
- Weighting of the groups, in order to come to an overall weight value.
- Classification of the results.
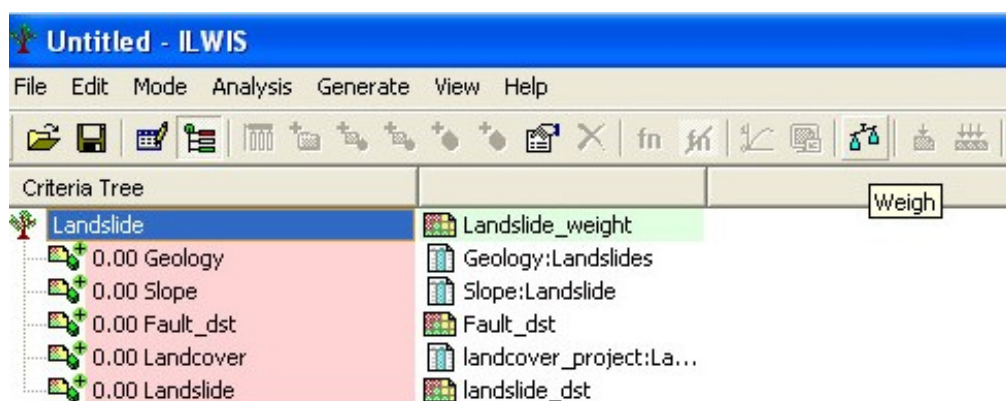
4.3   GETTING STARTED

Make a new sub-directory **\Landslide_map** on your working directory. Copy the data belonging to this exercise to this sub-directory.

- Double-click the ILWIS program icon.
- Change the working drive and the working directory until you are in the directory '\Landslide_map'
- Start the Spatial Multi-Criteria Evaluation operation, choose Raster Operations, Spatial Multi-Criteria Evaluation from the Operations menu in the Main window, or expand the Raster Operations item in the Operation-tree, and double-click the Spatial Multi-Criteria Evaluation item, or double-click the Spatial Multi-Criteria Evaluation item in the Operation-list.

A wizard appears that assists the user in creating a new criteria tree for:
- **Problem Analysis** - Analyze a problem situation using one set of maps as evaluation criteria. The criteria tree editor will start with an empty tree and a placeholder for one data set.
- **Design of Alternatives** - Perform analysis for designing alternatives/options using one set of maps as evaluation criteria, e.g. in suitability or vulnerability analysis. The criteria tree editor will start with an empty tree and a placeholder for one data set.
- **Decision making** from alternative options.
- **You can also open an existing criteria tree**
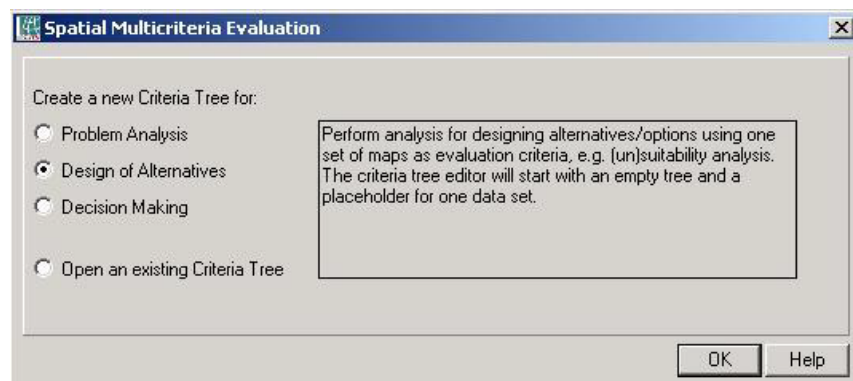
- Select **Problem Analysis**.
- Press OK.

The SMCE window appears. The SMCE window consists of a:

- **Title bar** with the name of the criteria tree (By default: 'New Goal')
- **Menu bar**. The SMCE window has seven menus, File, Edit, Mode, Analysis, Generate, View and Help.
- **Toolbar**, by default located just below the menu bar. The toolbar provides shortcuts for some regularly used menu commands (see also SMCE Help window, toolbar).

- Point to each item and the name of the command and a short description at the bottom of the status bar will appear.
- Criteria tree viewer to show and/or edit the criteria tree and to standardize and weigh the items of the tree.
- Status bar located at the bottom of the SMCE window. The status bar gives brief explanations on highlighted menu commands, the functionality of buttons in the toolbar and on selected items in the criteria tree.

4.4   MAIN GOAL

By default the name of the criteria tree is called 'New Goal'.
First you will change the name of the criteria tree. The name should be representative for the main goal you want to reach, for example landslide. You can either double click on the criteria tree called 'New Goal', or use the Edit mode on the toolbar. In both cases a menu 'Group' will pop up in which you can change the Name.

- Also give the name to file (no filename given). For example: **Landslide_weight**, because after these operations it will be created Landslide Weight map.

The criteria tree is a tree whose root is the main goal defined by the user, and whose leafs are the criteria that together evaluate the performance of this main goal. The branches divide the main goal into partial goals, and subdivide partial goals. The smallest criteria tree thinkable is a tree where the main goal itself is a criterion.
:
A criteria tree may contain:
- **Main goal**: One main goal is obligatory for any criteria tree. The main goal is also called the main root.
- **Constraint:** Constraints are binding criteria so no compensation is allowed. Areas in an input map (added as a constraint) that do not satisfy a constraint condition, will obtain a composite index value of 0, no matter how well these areas perform in any other criterion (factor). Constraints can only appear directly under the main goal.
- **Factor**: Factors allow for compensation. Poor performance in one criterion can be compensated by good performance in another criterion. Factors may appear directly under the main goal or under a group of factors (sub-goal), or even under a sub-sub-goal (objective). A factor can be a benefit (the higher the value, the better), or a cost (the higher the value, the worse).

- **Group of Factors:** [icon] A Group defines an intermediate or a partial goal. Under a Group, you can add one or more Factors and/or other Groups of Factors. Click the plus sign in front of a Group of Factors to expand the group.

For more details on the creation and filling of a criteria tree, refer to the Help function, Criteria tree viewer.

- Choose add factor (insert spatial factor) to add all factor (**Geology**, **Slope, Fault, Landcover, Landslide**)

- Give them name: **Geology, Slope, Fault, Landcover, Landslide**
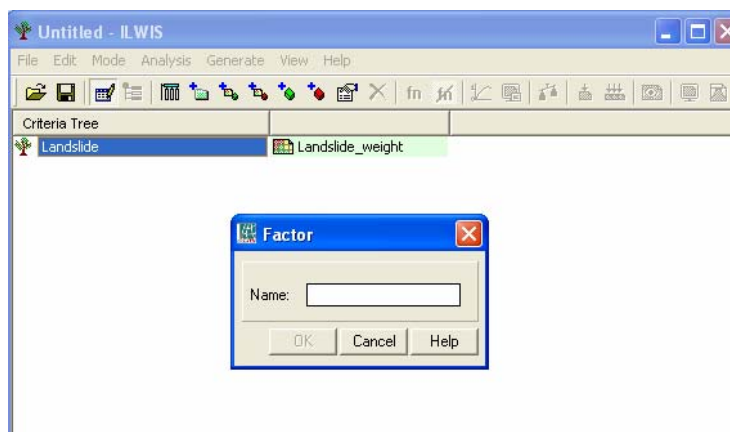
- Add another factor: **Slope**
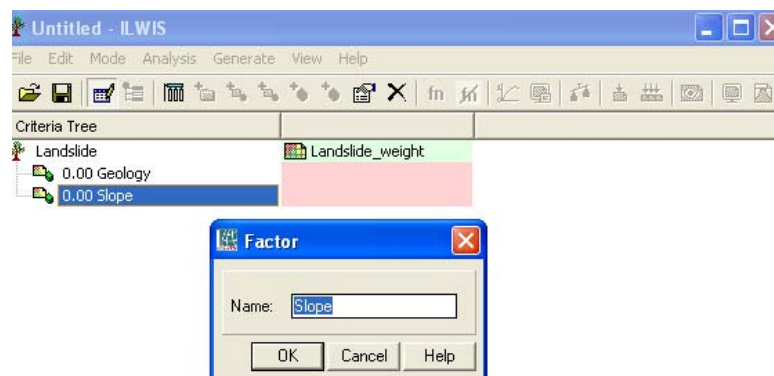
- Do the same operation for every Factor maps which are mains for landslide occurrence.

4.4.1   Generating buffer maps as input layers

Before adding Landslide and fault factor maps you have to create buffer maps for these factors.

- In ILWIS main window right click to the fault raster map, choose raster operation and Distance Calculation.
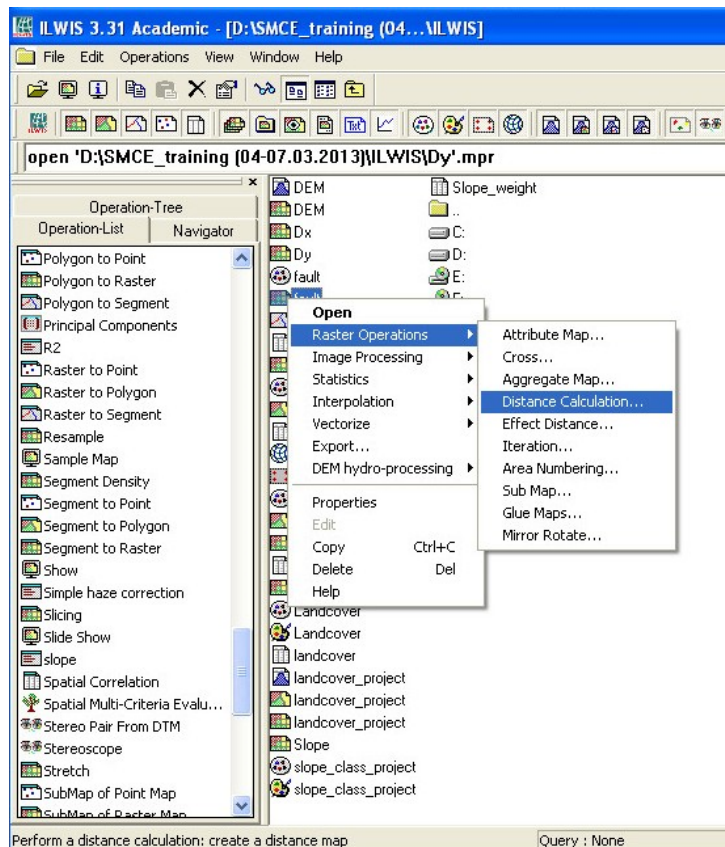
- Give the name of output raster map: **Fault_dst** and click to show.

Ilwis now will calculate distance from main fault and you will see the result like this:
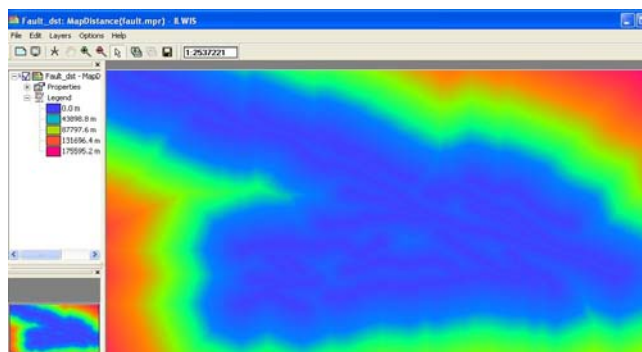
- Do the same to the Landslide raster map, calculate distance from landslide points, and give the name of output raster map: **Landslide_dst**.

Now we have all factor maps and we can continue doing SMCE.

- Add fault_dst map as one of the factor for landslide.
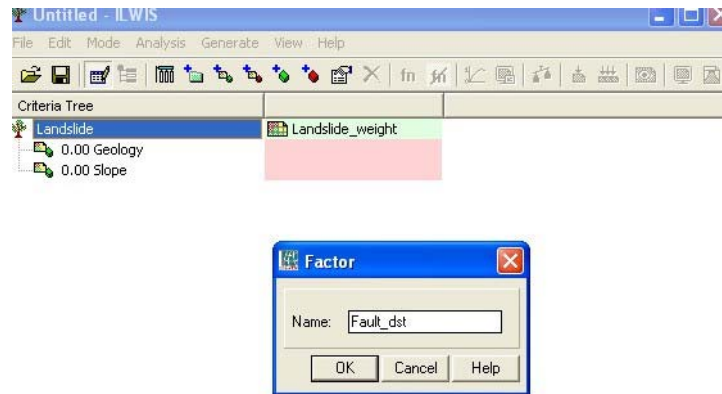
After adding all factor maps the table should look like this:
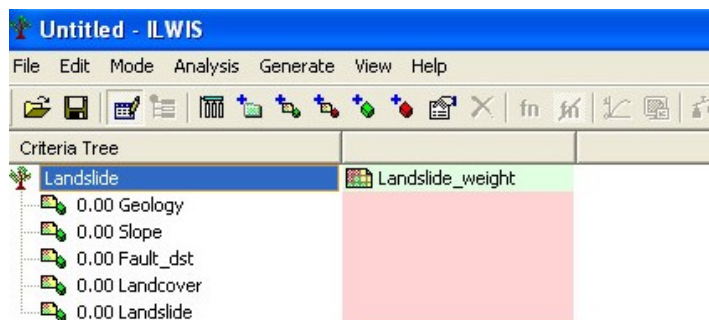
- Click red boxes and add one by one all factor maps.

If you finish all this operation now you can go to Multicriteria Analysis.
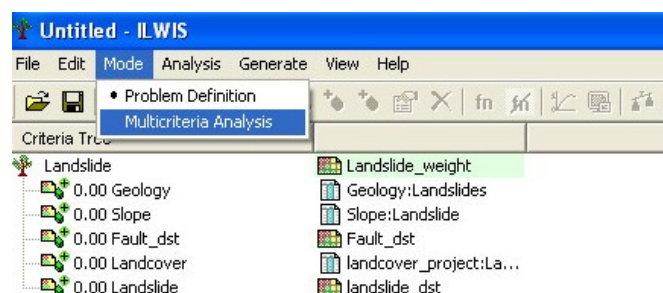
4.5   STANDARDISATION

In the Problem Definition mode, you have selected input data for your criteria (factors or constraints). These input data are various maps or attribute columns with a value domain, a class domain, or the Bool domain. The values in these input maps or columns express

different measurement units (e.g. distance, land use classes, percentages, etc.). In order to compare criteria with each other in a way that makes sense, they have to be standardised, i.e. transformed to the same unit. Moreover, different standardisation methods express different utility of input values. When standardising, depending on the type of input map, a dialog box will appear in which you can choose the "value function" by which the map or column values are converted to values between 0 and 1.

Standardisation possibilities are slightly different for factors and for constraints:

- **Standardisation of factors** (benefits and costs): output values range between 0 and 1.
- **Standardisation of constraints**: the output values are either 0 or 1.

Depending on the domain of the map or attribute column, one of the Standardize dialog boxes will appear:

- For value maps: Standardize Value Input.
- For class maps: Standardize Class Input.
- For boolean maps: Standardize Boolean Input.

A Standardize dialog box will only appear when you are in the Multicriteria Analysis mode, and when you selected a factor or constraint in the criteria tree viewer, and do one of the following:

- Choose Standardize from the Analysis menu in the SMCE window, or
- Click the Standardize button in the toolbar of the SMCE window, or
- Click a criteria with the right mouse button and choose Standardize from the context-sensitive menu, or
- Press the Enter Key, or
- Double-click a factor or constraint in the criteria tree viewer.

The output values will range between 0 and 1 when you are dealing with standardisation of factors (benefits and costs). Bad performance in one criterion can be compensated by good performance in another criterion.

Depending on the domain of the map or attribute column, a Standardise dialog box for a class input, a value input or a Boolean input will appear.

If your input map or table has a value domain, you have to realize next whether your factor is a benefit or cost!

For standardization of value factors, you must select one of the following standardization functions: Maximum, Interval, Goal, Convex, Concave

For more information and examples of standardization of value factors refer to the HELP window, Standardize Value.

- Standardize the factor maps using one of the above mentioned options.

4.6   WEIGHT ASSIGNMENT

Assigning weights is needed in order to indicate the relative importance of these factors with respect to the main goal or to optional sub goals.

Within SMCE three options to assign weight are possible:

- **Direct method** - The user has to specify weight values him/herself. These user-defined weights are automatically normalized.
- **Pairwise comparison** - The user goes through all unique pairs and assigns Saaty weights (in words). From these weights, normalized weights are calculated.
- **Rank ordering** - The user assigns a rank-order to the items. From this rank-order, normalized weights are calculated.

Weights have to be assigned to all the factors within a group and to the groups. Weights are always numbers between 0 and 1. Weights cannot be negative.
For the factors within a group, the sum of the weights of the factors equals 1. When a group only has one child (factor), this child automatically obtains a weight 1.
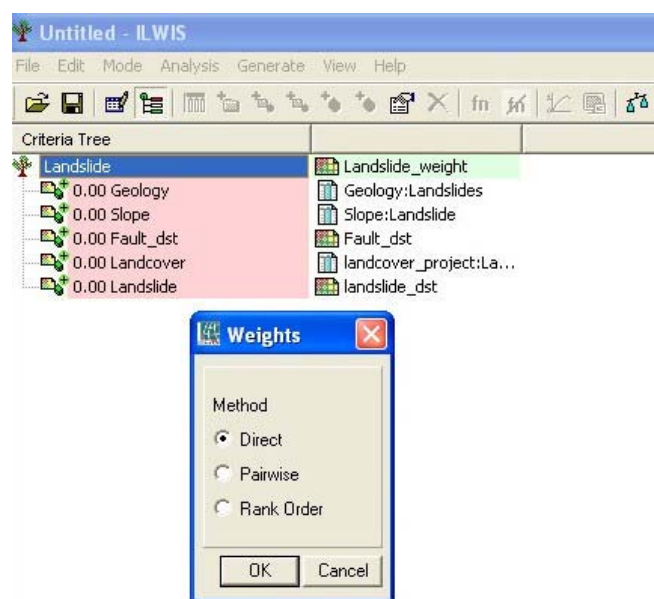
- Select one of these options and give the weight for all factor maps

4.7   CREATE THE FINAL MAP

- Now you can provide Landslide_weight map by clicking generate all outputs.
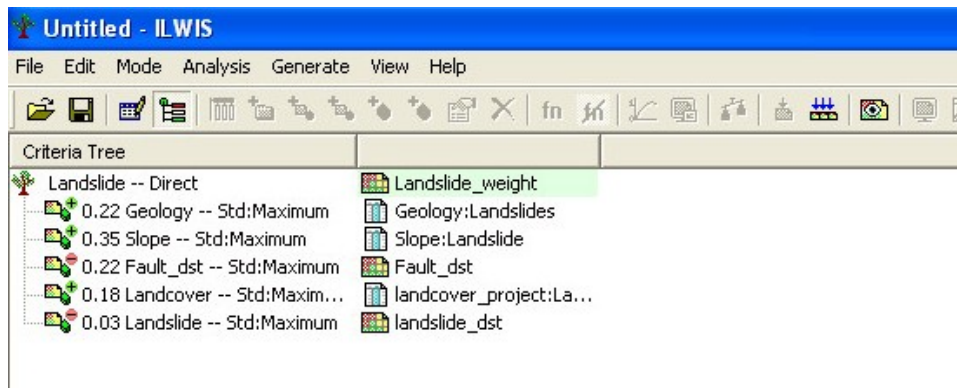
- Create class Domain (group) for Landslide susceptibility map.
- In the ilwis main menu click file-create-domain.
- Give to class and group domain name: Landslide_susc and click OK
- Open landslide_susc domain and click add item
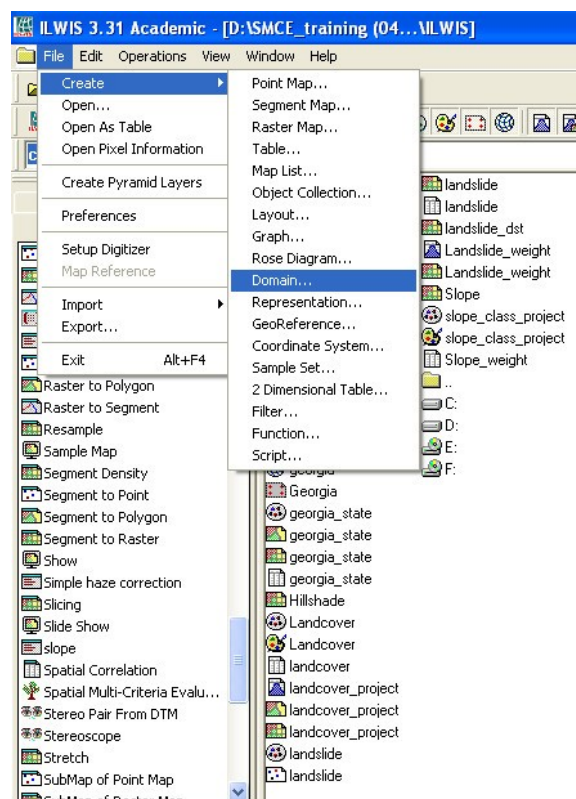
- Create 3 classes (High, Moderate, and Low) with its own upper boundaries and class names.

We can slice now (which means that you classify a value map into a class map based on thresholds that you have defined in the class-group domain) and create landslide susceptibility map.

- In the operation list click Slicing
- Choose raster map – landslide_weight
- Give name to output raster map – Landslide_susc
- Choose domain landslide_susc
- And click Show

Now Ilwis will generates Landslide susceptibility map in 3 classes (Low, Moderate, High) you can change colors of these classes.
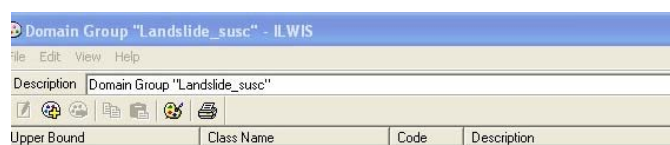
The final map is a simple landslide susceptibility map. In order to validate this map you should compare it with the historical landslides that have occurred in the area, and the evaluate whether most of the landslides happened in the high susceptibility class. To do this you can use the Cross operation.

- In the operation list click Cross
- Choose first raster map – **landslide_susc**
- Choose second raster map: Landslide
- Give name to output raster map – **Landslide**
- Choose output table: **Landslide validation**
- Copy the results into Excell and calculate: How much percentage of the landslides are in the high, moderate and low susceptibility classes

Based on the result you could improve the weights that have been used, or you could also decide to select more factor maps and redo the analysis. In practice we would use more factors maps than in this example, and would do this in an iterative manner.

- Compare your results with some of your colleagues and discuss the differences.
- Which other factor maps would you use when you want ot improve the map

5   NATIONAL SCALE FLOOD SUSCEPTIBILITY MAPPING IN PCRASTER

Expected time: 3 hours

Data: **Exercise_Floodhazards.zip**

Objectives: After this exercise you will be able to generate:

- Use PCRaster dynamic GIS software with a simple algorithm to make a national scale flood susceptibility map.

5.1   INTRODUCTION

This exercise makes extensive use of PCRaster, a freeware GIS and modelling language developed by Dr. Willem van Deursen (Carthago consultancy), Ing. Cees Wesseling (PCRaster Environmental Software) , Dr. Derek Karssenberg, Ing. Kor de Jong and the late Prof. Dr. Peter Burrough (Department of Geosciences of the Utrecht University). Details can be found on http://pcraster.geo.uu.nl. From this website you can download and install your personal copy. Be sure to install the updates as well.

For these exercises we use the windows shell NutShell which was developed to work with PCRaster by Victor Jetten (ITC). NutShell is not officially part of PCRaster and is supported separately. It can be found here: http://www.itc.nl/lisem/nutshell

NutShell version 3.5 is used in this tutorial

A number of publications and model examples relating to PCRaster can be found here: http://pcraster.geo.uu.nl/publications.html

Disasters have severe consequences for a large part of the earth's population and resources every year. They seriously challenge the progress towards almost all Millennium Development goals: poverty is increased, they form a direct threat to education and health, natural resources are affected which leads to a lower food security. Disaster statistics (ISNDR, CRED) clearly show an increase in frequency and magnitude, with earthquakes, hurricanes (and associated floods and landslides) and drought causing by far the most casualties and damage. This is directly related to population growth leading to an increase in urbanization and occupation of marginal lands, while a link with climate change or variability is becoming evident.

In the field of Disaster Risk Management we can generally define two important different phases: one is the disaster relief phase which is the action taken during and immediately after a disaster. This is the moment when national and international organizations (should) spring into action, to provide as much help as possible. Good and trustworthy spatial data is essential to this phase: where can I go, what has been destroyed, how much is the damage etc. The second phase is usually much longer, the disaster preparedness phase in between disasters. Many activities can be distinguished here, for which again spatial information plays an essential role. The modeling that you learn in this module is or should be beneficial for this phase.

A central concept in this is RISK. Risk is the overlap in space and time of hazardous processes, i.e. natural processes that may cause a disaster, and the vulnerability of so called

"elements at risk". These are people, property, infrastructure and natural resources (see fig 1.1). A way of looking at this is to see risk as the potential for disaster, or disaster as the materialization of risk.

However, to say anything sensible about hazardous processes that cause disasters we need to realize a few things. It starts with a real world question, for instance "how safe are we" or "how many victims or damage can we expect during a flood". The purpose of this exercise is to carry out a preliminary flood susceptibility assessment at a national scale. This is part of the Flood Directive of the European Union, and it is meant to give a first impression of where floods can be expected.

5.2   INSTALLING PCRASTER

- Make a folder on your own D-drive called " Matra_2013".
- Go to T:\Kingma and copy the zipped folder PCRaster_Flood to your D-drive. (Do NOT work directly on the T:\ drive but in your own directory)
- This folder contains installation files and exercise files.
- Unzip this folder PCRaster_flood .
- First install PCraster
- Second: Install Nutshell but run as administrator.
- Make a shortcut to NutShell.exe on your desktop.
- When you start NutShell you get a window about an update, ignore it.

You are now ready to start this tutorial!

5.3   ABOUT PCRASTER

The modelling is done with the PCRaster GIS, which is a freeware GIS and modelling language that can be used to build "spatial dynamic models". The term dynamic is used here to indicate that you model and simulate processes that change over time, for instance moving matter (water and sediment), changes in the landscape etc. The website http://pcraster.geo.uu.nl gives you examples of scientific work done with PCRaster. It has a great advantage that the threshold to learn it is very low, and the disadvantage that it cannot do certain advanced mathematical operations. For our purpose it is however more than sufficient. PCRaster also has extensive map algebra functions to manipulate raster maps.

PCRaster consists of two main programs: **pcrcalc** is used for GIS operations with maps and tables and execute the model scripts. The program **aguila** is the visualisation program to see graphs, maps in 2D, 3D and series of maps as a movie. The complete set of programs is:
- **asc2map** - Converts from ascii file format to PCRaster map format
- **col2map** - Converts from column file format to PCRaster map format
- **map2asc** - Converts from PCRaster maps format to ascii file format
- **map2col** - Converts from PCRaster map format to column file format
- **resample** - resample maps to a different cell size, cut out maps or join maps.
- **table** - Creates a table on the basis of one or more maps.
- **mapattr** - Create new maps or change map attributes (functionality directly available in NutShell)
- **legend** - DOS based legend creation(functionality directly available in NutShell)

- **mapedit** - simple graphical map editor (part of NutShell).

Conversion to and from PCRaster can be done by the software at: http://www.gdal.org
ILWIS for instance talks to PCRaster with the GDAL software.

To facilitate the use of PCRaster we will use a windows based shell that has many built in features to take advantage of the PCRaster software: it is called **NutShell**. NutShell is a separate development and can be found at http://www.itc.nl/lisem/nutshell. You will start learning PCRaster by looking at the first dataset and creating a number of maps.

5.4 EXPLORING THE DATABASE WITH PCRASTER

For this exercise, we work with a digital terrain model of Georgia, located between the Black Sea and the Caspian in the Caucasus. The area has five different climatic zones ranging from mountainous to desert. First, we will learn how to work with maps in PCRaster and Nutshell: displaying and overlaying.

The Nutshell icon

- Open Nutshell by clicking on the icon on your desktop. First you have to tell NutShell in which directory where you are working. Go to the directory with the database (**D:\Matra_2013**) in the explorer part of NutShell and click on the set work directory icon ( ). NutShell will store your work directory for future sessions. The Nutshell application has three windows (see figure 1) which we will refer to in the exercises: the command window (upper left), the explorer (lower left) and the model editor (right).
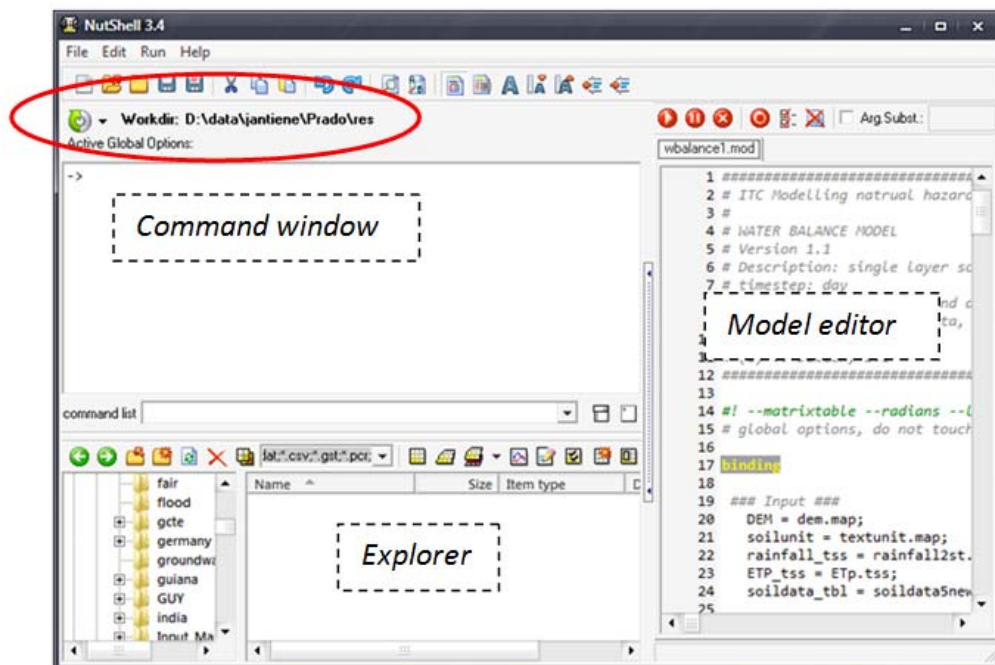
Figure 1. NutShell window with the three main parts. The red circle shows where to set a work directory.

In this directory you will find different maps of Georgia. PCRaster maps have a .map extention. For this exercise the maps are organised in two sets.

- **demGeorgia.map**: ASTER GDEM digital elevation model resampled from a cell size of 30 m to 100 m
- **cloneGeorgia.map**: mask map for the outline of the country
- **ldenGeorgia.map**: line density map based on secondary road density in km/km2.
- **demXS.map**, **cloneXS.map**, and **ldenXS.map**, which contains the same type of data, but for a much smaller area.

- We will first look at a few maps to see how the display program `aguila` works. Look first at the elevation map: find the file `dem.map` in the NutShell explorer and double click on it. This will open `aguila` and display the map. You can zoom in or out with the scroll wheel of your mouse and return to the initial view by pressing the icon 🔍.
- You can see information of the cell you are pointing at by opening the "*Cursor and values*" window: ✛ and move the cross hair with ctrl-left mouse button. To see the cell values. Using this feature calculate the longest north-south and east-west distance in the area. The units are meters.
- You can also influence the way it is displayed by double clicking on the legend, where you can change e.g. the colour palette or the display class boundaries.
- If you want to see the map in 3D, highlight it in NutShell and click on the icon: 🗺 to open `aguila`. The arrow keys and the 'n' and 'm' keys move the landscape.
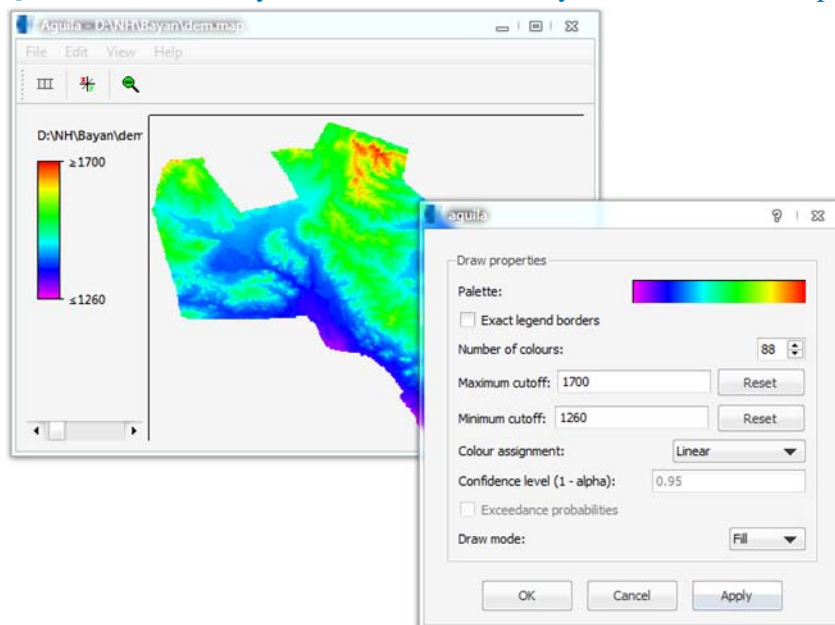
- To get cartographic information highlight any map in the database and press on the icon:🗺. You can now see the nr. of rows and cols, cell size and coordinate information (see figure below). There is no indication of cell size units, the user has to remember if the cell length is in m, km etc.

WARNING: you can actually change the cell size here but it will not resample the map, just change the header information. If you change the cell size of one map in the database it will not fit with the others anymore. `pcrcalc` can only do operations on maps with the same header information.

GIS operations in PCRaster are done with the spatial calculator pcrcalc. PCRaster is command-line based, not menu based. The syntax is always:

pcrcalc result = operation

There are over a hundred GIS, arithmetic and logical operations that can be done with **pcrcalc**. The result usually a map, but can also be a table. Maps have their own PCRaster binary format, tables are text files. Press Ctrl-F1 in NutShell to see the complete list. Single operations on maps are done by typing a pcrcalc command in the upper left "command window" in NutShell, display of maps and graphs is done with **aguila** by double clicking on the file in the explorer part of NutShell.
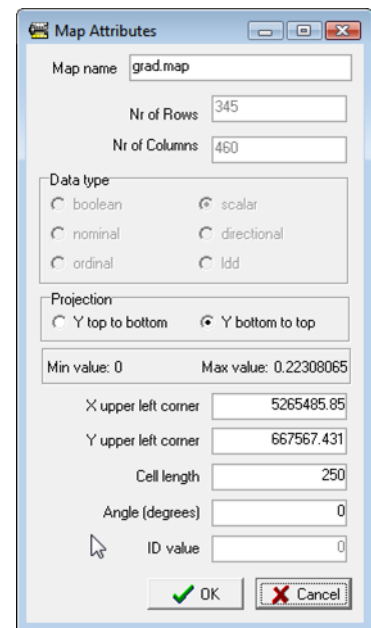
- A slope map is constructed as follows. Type the following command in the command window (upper left window in NutShell) at the '->' prompt:
  pcrcalc grad.map=slope(demXS.map)
- and press <enter>. A map called `grad.map` is now created with the pcrcalc operator "**slope**" and appears in your list of files in the explorer part of NutShell (new files are first shown at the end of the file list, so scroll down). Studying the slopes is good practice when you are modelling the water balance (runoff). Look at **grad.map** by double clicking on it to open **aguila** and note how flat the area is.
- You can also view the slope map in 3D as follows. Highlight the **demXS.map** and click on the coloured 3D icon, and select "set aquila base maps"(version 3.5):
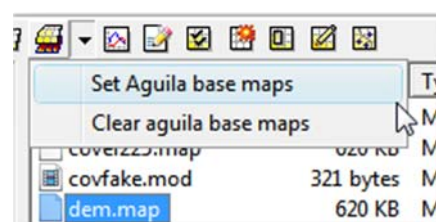
- this makes the DEM the base map on which the slope is 'draped'. Next highlight the map grad.map and click on the 3D icon itself: . Aguila is now opened with the slope map in 3D. This can be very slow and take up memory, so close **aguila** when you are done with it!
- To practise the command line approach we can make a shaded relief map from slope and aspect. First make an aspect map:
  pcrcalc asp.map=aspect(demXS.map)
- A simple formula for shaded relief is (Kennelly, 2008):

$$shade = 255 \cos(I) \sin(S) \cos(A - D) + \sin(I) \cos(S)$$

Where: 255 is a scaling factor, *I* and *D* are the inclination (sun elevation angle) and eclination (sun compass direction), and *S* and *A* are the slope and aspect of the terrain. Basically the equation calculates in how far a gridcell is pointed away from the incoming solar radiation. With an inclination I = 35 degrees and a declination D = -45 degrees (NW) the PCRaster command is:

```
pcrcalc shade.map=255*cos(35)*sin(grad.map)* cos(scalar(asp.map)+45) +
                          sin(35)*cos(grad.map)
```

Note: the `scalar` operation is used to change the data type of the aspect map from 'directional' to scalar. Display the shade map for an impression of the area. Open the map in aguila and select an appropriate colour grey tone palette to display the shaded relief: double click on the legend, and then double click on the palette, select the second palette.

5.5   THE NATIONAL SCALE FLOOD SUSCEPTIBILITY MAP

An algorithm has been developed by the Joint Research Center of the European Union for flood hazard and risk mapping at the pan-European scale {Roo, 2007 #3}.

A first estimate of the flood hazard is determined from the height above the river. It computes the elevation difference between a specific grid-cell and its closest neighboring grid-cell containing a river, while respecting the catchment tree-structure: in this way a grid cell can never be linked to a river in another (sub)-catchment. The method is defined by the following main steps: (1) determination of the river network derived from the digital elevation model, (2) define the river as 'pits' – outlets of individual small local catchments. For each of those pits, the local catchment draining into this pixel is defined using the 'catchment' function (Figure 2). (3) the elevation of the river pixel (the pit) is given to this entire sub-basin: the river pixel is assigned the elevation from the DEM. Finally, the difference between the original DEM and the DEM with the local river altitude is estimated as the height above the river. This local height difference is sliced into three susceptibility classes and overlayed with a map of the built-up area.
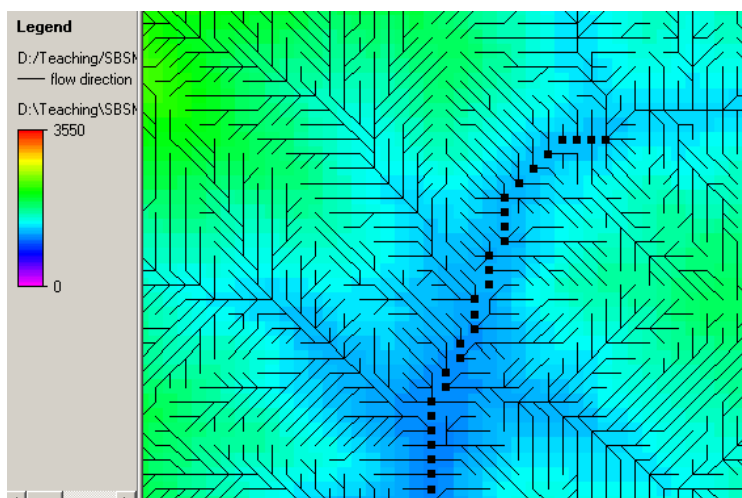
Figure 2. Aguila window with the dem, and the river network as pits (black squares)

Let's see how we can take these steps in PCRaster. The next chapter will take you through the process step by step.

5.5.1 Create a Stream Map

The first thing we need is a stream network, which is part of a map with surface drainage directions. PCRaster has algorithms to create such a map based on the steepest slope. A drainage network in PCRaster is called a LDD map (Local Drainage Direction). The pcrcalc operation is lddcreate. This command creates a continuous network that connects every cell to the outlet of the catchment. To do that it has to ignore "pits", i.e. local depressions without an exit. These can be real depressions, or artefacts from the creation of the DEM. Leaving these pits in the LDD map would interrupt the flow and guide it to "sinkholes", which we will impose on purpose in the next step. To ignore pits in a DEM and create a continuous network, the command lddcreate uses 4 thresholds values that allow the user to control this process (by trial and error):

LDD=lddcreate(DEM,"outflow_level","core_volume","core_area","pit_catchment")

These 4 threshold variables are values that determine if local depressions (pits) are ignored when creating the drainage network (see fig 2). These thresholds work as follows:

- If all thresholds are set to 0, all local depressions are considered as end points, and many small networks may be created (depending on the nature of the DEM).

- If the values are set to some arbitrary very high value (such as 2e10), all depressions will be temporarily removed and a single network is created.

- If you have different threshold values, the smallest value will determine which size of depression is still ignored or considered. It is an arbitrary, empirical process to help the user create a network he/she wants.

NOTE: the DEM is *not* changed by this operation, pit removal is done temporarily. You can permanently remove pits and alter the DEM with lddcreatedem.
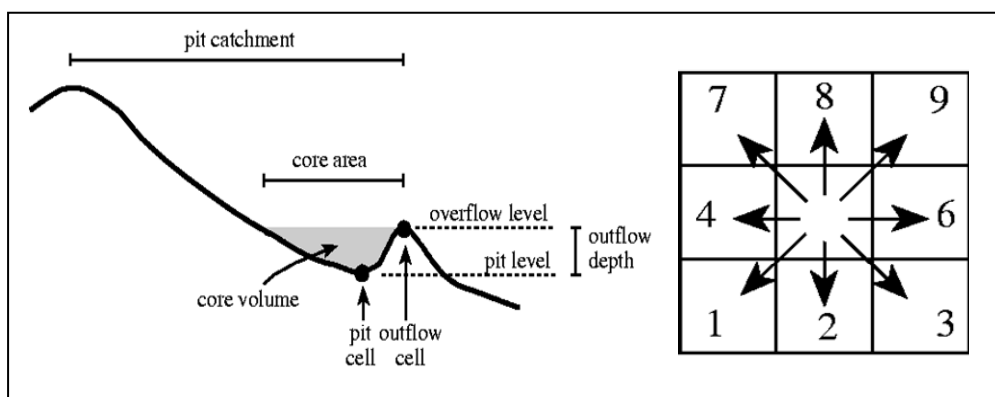
Figure 2. Graphical representation of the 4 pit removal thresholds (left) and LDD directions (right) (source: PCRaster manual).

Furthermore there are two global options with lddcreate: "--lddin" and "--lddout". The option "--lddin" forces all flow directions towards the inside of the catchment, resulting in one final outlet point, even if at the boundary of an area some slopes are directed towards the outside. This map will also be used to route overland flow to the streams and the peakflow to the outlet.

- Make the LDD map with the command:

  pcrcalc--lddin ldd.map = lddcreate(demXS.map,1e20,1e20,1e20,1e20)

- Look at **ldd.map** and **zoom in** to get an idea of how it is composed.
- The outlet is found by the command:

  pcrcalc outlet.map = pit(ldd.map)

- In PCRaster there are several functions to accumulate "matter" over a network. The operation for that is called **accuflux**. This operation takes the value in a cell, adds the values of all cells upstream to it. The ldd is the network used for this accumulation. Give the following command to get a cumulative drainage map:

  pcrcalc upArea.map=accuflux(ldd.map, 1)

- Look at this map in aguila, if necessary choose a logarithmic legend.
- What is the total number of grid cells in the catchment?

- You can analyze your stream network with the command:

  pcrcalc so.map = streamorder(ldd.map)

- This gives you the stream order of the river system in your catchment.
- Make a river network map stream.map based on the so.map by giving a pcrcalc command if(…) that selects all maps that are of stream order greater than 6. Note that PCRaster needs a specification of the output type of the map, which can be boolean, nominal, ordinal, scalar, or directional. Here, we choose nominal.

  pcrcalc stream.map = nominal(if(so.map>6,5))

This map determines maybe more than you realize. Wherever there is a stream cell a pit will be computed in the next step, which determines the height above the river. Choices we made here, such as choosing the minimum stream order will directly influence the final output. Parameterizing the method should be done afterwards to make it appropriate for the study area. Finally it is very important that the river network follows the DEM. Often if the rivers are digitized separately, they do not occur exactly at the deepest point of a valley which gives hydrological errors. In that case it is better to generate the river network from the DEM.

5.5.2 Mapping flood susceptibility

In order to be able to compute the height above the river, we need to assign the river height to the whole catchment that drains into that river pixel. We will do that by altering the drain direction map. It consists of three steps.

- Firstly, we change the data type of the `ldd.map` from 'directional' to 'nominal' to enable map overlaying.

  pcrcalc draindir.map = nominal(ldd.map)

- Visualize this map in Aquila to see the difference between the `draindir.map` and the `ldd.map`. Next, type in the following two commands alter the drain direction of the area. The `cover` operator merges `stream.map` and `draindir.map`, thereby

substituting missing values in the first map with data from the second map on a cell by cell basis. The `lddrepair` operator makes a properly connected `ldd` of the new map.

```
pcrcalc newdraindir.map = cover(stream.map, draindir.map)

pcrcalc lddRiver.map=lddrepair(ldd(newdraindir.map))
```

- Question: What is the value of a pit in the drain direction map?
- Question: How does the merging of the two maps lead to pits at the stream location?

In this exercise, we will calculate the height above the river. First, we will determine the catchment area for all pits at the location of the main rivers.

- Type in the following lines at the command prompt in Nutshell:

```
pcrcalc riverID.map = uniqueid(boolean(stream.map))

pcrcalc IDnominal.map = nominal(riverID.map)

pcrcalc localCatchments.map = catchment(lddRiver.map, IDnominal.map)
```

- Visualize the map with the local catchments and overlay it with the `lddRiver.map`. Zoom in to see the pits of the local catchments. Calculate the local height above the river by:

```
pcrcalc localRiverHeight.map = areaminimum(demXS.map,localCatchments.map)

pcrcalc heightAboveRiver.map= demXS.map-localRiverHeight.map
```

The first command computes the minimum value in the catchment based on the dem. This is automatically the height of the river as that is the pit of the catchment. As heights above the river of more than 9 meters is not very likely, we mask out these areas using the following command.

- Visualize the dem and the map with the height above the river in two separate windows and inspect the results.

```
pcrcalc heightAboveRiver10.map = if(heightAboveRiver.map lt 10,
                          heightAboveRiver.map)
```

- Question: How can the the sudden jumps in this map be explained?
- Question: What is the reason that small areas exist in the map that are not connected to the main river?

Since we are creating a flood hazard map at a national scale based on the ASTER GDEM, we need to downgrade the final map. There are two reasons for this. Firstly, the hazard analysis is not based on physically based hydrodynamic modeling, and secondly the errors in the dem are around 7 m, which prohibits detailed analysis. These errors can be even larger for the bathymetry of the large rivers, since the ASTER only represents the water surface, and not the underlying bottom height of the river. Therefore, we need to clean the map by deleting small disconnected areas, classify the hazard and smooth the output.

- Small disconnected sections can be deleted by:

```
pcrcalc clumps.map = clump(boolean(if(heightAboveRiver.map lt 10, 1)))

pcrcalc clumparea.map = areaarea(clumps.map)

pcrcalc heightAboveRiverTrimmed.map = if(clumparea.map > 200000,
                          heightAboveRiver10.map)
```

- Explain in your own words what these three lines do. Check with the manual under the help tab what the operators `clump` and `areaarea` do. Next, we will create a classified map for flood susceptibility, which is subsequently smoothed.

```
pcrcalc floodClass.map = ordinal(lookupscalar(reclass.txt,
                   heightAboveRiverTrimmed.map))
pcrcalc classSmooth.map = if(floodClass.map > 0,
             windowmajority(floodClass.map, 300))
```

The operator `lookupscalar` will slice the map based on the class boundaries as specified in the `reclass.txt` file. Open the `reclass.txt` file in Nutshell and see what are the class boundaries. `windowmajority` will smooth the map based on a 300 m window. It assigns the class that forms the majority in the local neighbourhood.

- Question: The smoothing by the `windowmajority` has been nested in a conditional statement (if, then, else), which states that this should only be carried out at those locations where `floodclass.map > 0`. Why is that necessary?

Flood risk is the overlay of the flood hazards with the elements at risk. Ideally, we would have information on all the houses, or builtup areas. For Georgia, this is not available, therefore we need to use another source of information. One option would be to use remote sensing. Another is to use freely available GIS data. In this exercise we will use street locations from OpenStreetMap (OSM): http://downloads.cloudmade.com. Here you can find field-mapped roads, even very small ones. Assuming that a high road density indicates builtup area, we can map builtup areas using OSM data. The road density map is given in `ldenXS.map`.

- However, not every road indicates houses, so we need to threshold the road density map to make a builtup area map:

```
pcrcalc builtup.map = boolean(if(lden.map>7,1))
```

- To know the location of the builtup areas that might be flooded, we type:

```
pcrcalc builtFloodSusc.map = if(builtup.map, classSmooth.map)
```

- In the end, we need a summary of the area of the builtup area that is covered by the different flood hazard classes. PCRaster has the possibility to aggregate results into table output of maps:

```
table --unitcell builtFloodSusc.map SuscOverview.txt
```

- This will write the number of cells of each of the three flood hazard classes to a new file called `SuscOverview.txt`.
- Question: What area is larger, the builtup area covered by class 1, or by class 3?

5.6   SCRIPTING, AND SENSITIVITY

Until now, we have typed all the commands on the command line. However, if one wants to redo the whole procedure for a different area, or using different settings all the work needs to be redone, which is a waste of time. We can use scripts to reuse the code that we developed. In the file NatFloodHazard.mod all the commands that you typed in have been listed.

- Open the .mod file in Nutshell. Note that each line needs to end with a semicolon, ;, and that a # indicates a comment line. Execute the script by pressing this button , or by hitting F9. In the command window a message will appear that the script is running:

<div align="center">

`pcrcalc -f NatFloodHazard.mod`

</div>

Wait until the script is ready. This may take some time. Especially the creation of the local drain direction map. Existing files will be overwritten, therefore in the first three lines in the script, we make a connection between the map input.

- Next, we will do a simple sensitivity analysis for one of the parameters. One of the arbitrary choices that we made was the stream order used for the mapping of the main rivers:

<div align="center">

`stream.map = nominal(if(so.map>6,5))`

</div>

- Comment out the line where the ldd was created to save time, and run the script once more. Now rename the final output map in the explorer window from `builtFloodSusc.map` to `builtFloodSusc6.map`. Indicating that stream order 6 was used.
- Rerun the script with stream order 5, and once more with stream order 7. Rename the output `builtFloodSusc.map` to `builtFloodSusc5.map` and `builtFloodSusc7.map`, respectively. Create table output for the three maps using:

<div align="center">

`table --unitcell builtFloodSusc5.map SuscOverview5.txt`

`table --unitcell builtFloodSusc6.map SuscOverview6.txt`

`table --unitcell builtFloodSusc7.map SuscOverview7.txt`

</div>

- Question: What is the fractional change of change in the output due to changing the main rivers based on stream order 7, instead of 6?
- What is the change between stream order 5 and 6?
- For now, we will accept the settings and carry out the flood susceptibility for the complete territory of Georgia. Open the script once more and make the following changes:
  - Set the stream order back to 6
  - Uncomment the creation of the `ldd.map` in line 21
  - Change the input data in the initiation section

<div align="center">

`# Initiate maps`

`demXS.map = demGeorgia.map;`

`clone.map = cloneGeorgia.map;`

`lden.map = ldenGeorgia.map;`

</div>

- Run the script once more. This can take a long time due to the high resolution, the large study area, and the noisy dem. Especially ldd creation takes much time. Expect to wait up to 30 minutes, or more for the finalization of the script depending on computer power. After that create the table output.
- With this method, you have created a first map of the flood susceptibility at a national scale.
- Question: What are the positive aspects of this method?
- What parts could still be improved, and how would you do that?
- What data and methods would be required for that?

Reference: Roo, A., Barredo, J., Lavalle, C., Bodis, K., Bonk, R., 2007. Potential Flood Hazard and Risk Mapping at Pan-European Scale. In: Peckham, R.J., Jordan, G. (Eds.), Digital Terrain Modelling. Springer Berlin Heidelberg, pp. 183-202.

6 GENERATING A QUALITATIVE MULTI-HAZARD INDEX USING SPATIAL MULTI CRITERIA EVALUATION

Expected time: 2 hours

Data: **Exercise_multihazards.zip**

Objectives: After this exercise you will be able to generate:

- A hazard index, which combines 10 diferent hazard maps for the country of Georgia, and generate a composite index map showing the ranking of these hazards.
- All procedures are based on Spatial Multi Criteria Evaluation
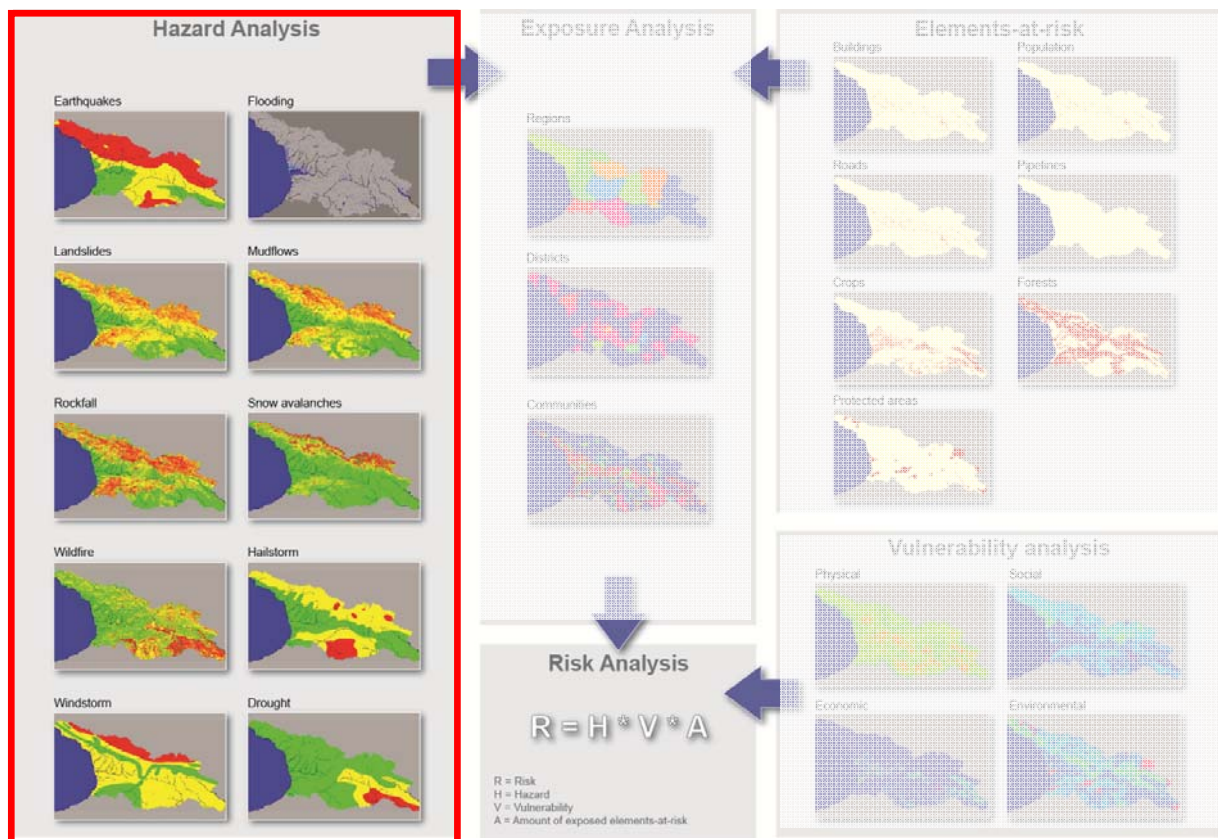
6.1   INTRODUCTION

For this exercise we need a large amount of data which has been generated in the framework of the MATRA project explained above. All data is in raster format, and the raster maps have a pixelsize of 100 by 100 meters, so representing 1 hectare. After looking a a simoplified procedure in the previous exercise for generating a landslide susceptibility map, we will now combine all available hazard maps into a composite hazard index. This index

map will indicate which part of Georgia has most problems in terms of multiple hazards. Also for this procedure we will use a spatial multi-criteria evaluation.

6.1.1 Hazard input data

For the hazard assessment 10 hazard maps are available, for which the characteristics are given in the table below:

Map	Hazard	Description
Hazard_EQ	Earthquake Hazard	Made using SeisRISK programme and the map whihc was used shows the Peak Ground Acceleration that has a 10% probability of exceedance in 50 years.
Hazard_FL	Flood Hazard	For the flood discharge analysis a total of 108 hydrological stations were used, and magnitude-frequency analysis was done. Flood heights were estimated for 3 return periods (10, 50 and 100 years). A simple model was used to extend the flood over the downstream areas. A script was Used in the freeware dynamic GIS PCRASTER to compute the height above the river based on a Digital Terrain Model (DTM). The DTM was based on the ASTER GDEM v2. The script determines the location of the main rivers derived from the stream order of the water courses. Then the height above the river for each location in the study area was computed by forcing the catchments to have their outlet at the location of the river. The height of the outlet was assigned to the whole catchment, and was subsequently subtracted from the DTM..
Hazard_LS	Landslide Hazard	Made with Spatial Multi Criteria Evaluation using slope, landuse, geology, rainfall, earthquake, road, and river information, and validated wth historical events
Hazard_MF	Mudflow hazard	
Hazard_RF	Rockfall Hazard	
Hazard_SA	Snow Avalanche Hazard	Made with Spatial Multi Criteria Evaluation using slope, altitude, slope direction, landuse and MODIS derived snow cover maps, and validated wth historical events
Hazard_WF	Wildfire Hazard	Made with Spatial Multi Criteria Evaluation, using different submodels, for Fuel availability, Fire detection, Weather, Response, and Ignition sub-models.The validation approach undertaken for this study was based on crosschecking the burned areas from the MODIS Burned Area Pixel product with the Wildfire Model.
Hazard_DR	Drought Hazard	Made using a number of indices calculated from rainfall stations, such as
Hazard_WS	Windstorm hazard	Made from interpolating maximum windspeeds recorded within a 50 year period in meteorological stations.
Hazard_HS	Hailstorm hazard	Made from recorded number of days with hailstorms based on meterological stations.

Figure: the 10 hazard maps used in the exercise.
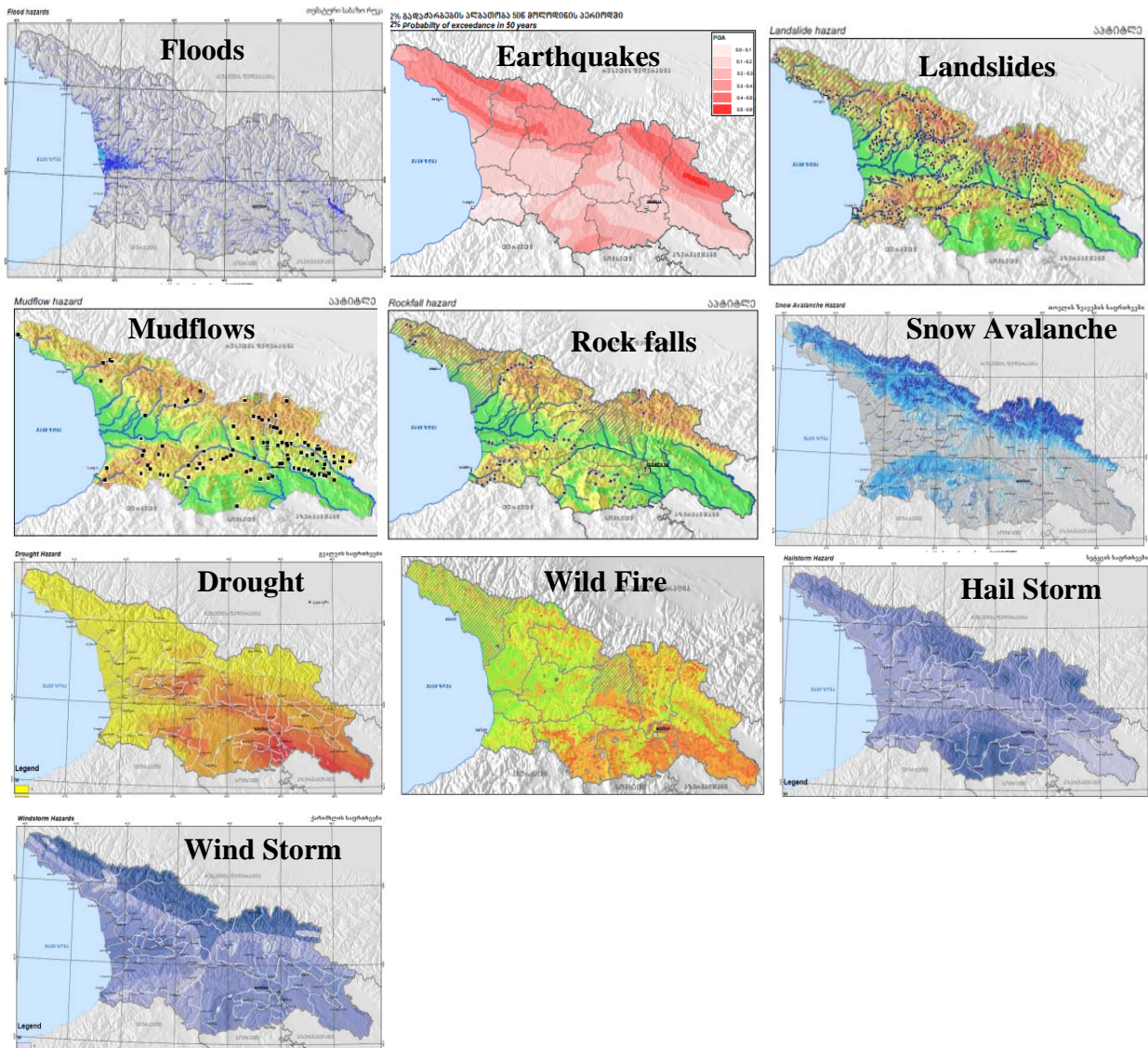
Tasks:

- If you are interested to know more about how the hazard maps have been made, you can read Chapter 3 of the Risk Atlas.
- In ILWIS, open the various hazard maps indicated in the table above, and check their content.
- Also use PixelInformation ([image]). Pixel info allows you to interactively inspect class names, IDs or values in one or more raster, polygon, segment and point maps and attribute values in attribute tables. You can use Add map and then add all hazard maps one by one. Use Option/Always on top, and browse through the map while you read the information for the sme pixel for all other maps.

6.2   GENERATING THE HAZARD INDEX MAP

In this step we will generate in the ILWIS Spatial Multi Criteria Evaluation (SMCE) software tool, a problem tree that will be used to calculate the hazard index. Below we will take you through the procedure. Later on you can do it yourself for the other groups.
Which criteria to use, and how to order them? This is often one of the most difficult parts of the procedure.

- Select *Operations / Raster Operations / Spatial Multi Criteria* Evaluation. Select the option Problem Analysis. An empty problem tree is opened.
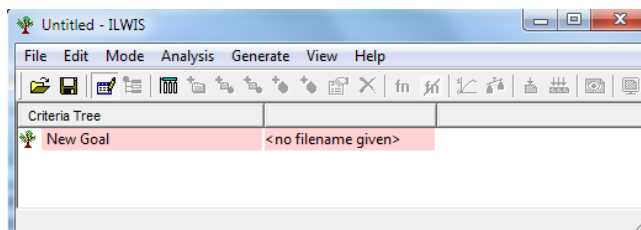
- Change the goal (right click select Edit)to: **Hazard_Index**, and the name of the output map (in the right side) to **Hazard_Index**.

- Click on **Hazard_Index** and click on the insert group icon or Right click on it and select *Insert group*. Add the groups: **Geological_hazards**, **MassMovement_hazards**, **Environmental_hazards**, and **Flood_hazards**.
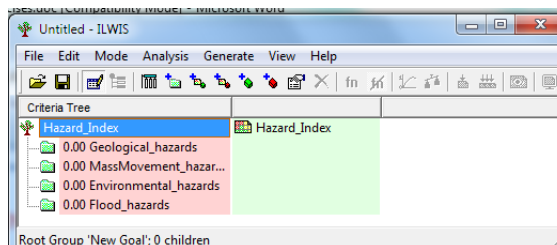
- Include the various spatial factors and groups for the individual criteria, as indicated above in the example by right-clicking on the individual criteria and inserting the spatial factors or click the insert spatial factor icon .
- Note: all parts indicated in red should be completed before you can make the output map.
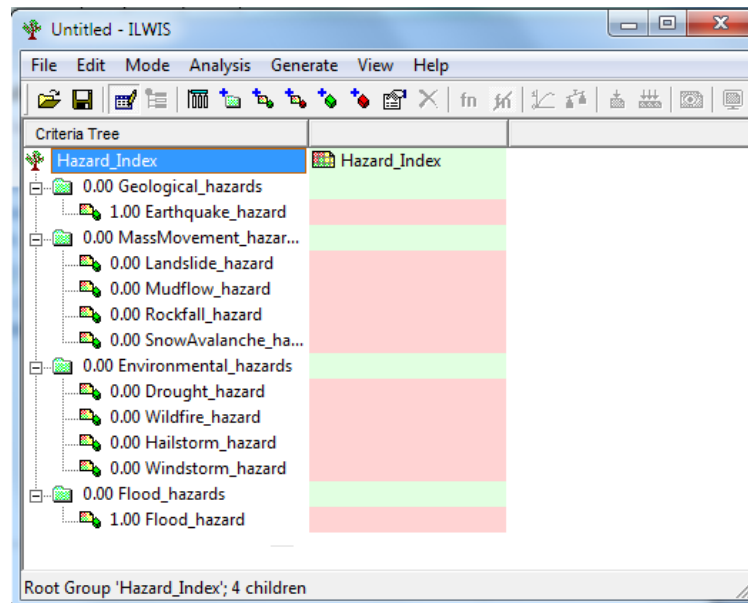
Next you will have to assign the spatial data that is relevant for each of the criteria that you have defined. These are mostly coming from maps or from tables associated to maps

- Important: SMCE works only with raster maps. The Rastermaps should all have the same georeference (the file defining the boundaries of the raster map and the pixelsize).
- Add the raster maps to each of the indicators (e.g. Hazard_EQ = earthquake hazard, Hazard_LS = Landslide hazard, Hazard_MF= mudflow hazard etc.)
- Do the same for the other main subgoals and create the tree that looks like the one on the right
- Save the criteria tree as **Hazard_Index**
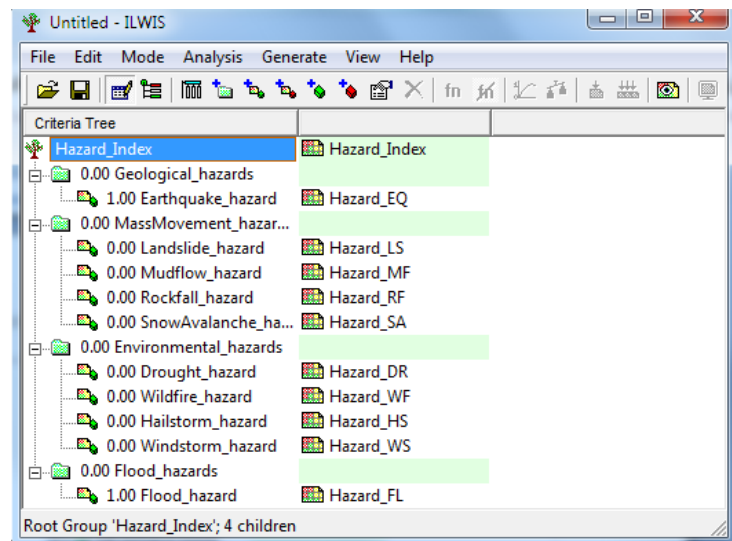
Once you have done this the decision tree for the hazard assessment has been made and all the input and output maps have been defined. However, how should we standardize and weight them?

6.2.1 Standardization of the factors.

All of the hazard maps that we are using in this exercise have been reclassified into 4 or 4 classes:

Hazard class	Description	Standardizing
High	Most events occur in this class (80 %)	1.00
Moderate	Some events occur in this class (15 %)	0.66
Low	A few events occur in this class (5 %)	0.33
None	No events will occur in this class (0%)	0.00

Each of the hazard maps is linked to the same domain, which can be seen as a legend.

- In the data window double click on the icon 🔅 **Hazard**. You see it has the same classes as in the table above.
- Double click on the icon 📊 **Hazard.** This is the attribute table linked to the domain Hazard, and through this domain to each of the hazard maps. You see that we have made a column **Standardizing**, which has the same values as in the table above (these could be changed if you think that is better…)
- Close the table and go back to the Multi criteria tree **Hazard_Index**. We are now changing the mode into the **Multi-Criteria analysis mode**. Click on the icon 📋 or select *Mode, Multicriteria Analysis*. The criteria tree now looks like the one on the right. All the red areas should be dealy with.

Next we need to standardize these different values, and normalize them to values ranging from 0 to 1. Standardization and the design of value functions is a crucial part of the SMCE. Different standardization methods express different utility of input values. When standardizing, depending on the type of input map, a dialog box will appear in which you can choose the "value function" by which the map or column values are converted to values between 0 and 1.

- Double click on the red area indicating **0.00 Earthquake_hazard**. Now a window opens in which you can select the table Hazard, and the column Standardizing, which will convert the data into a range between 0 and 1.
- Do the same for the other indicators as well. Since they are all linked to the same domain, and have the same classes, we can use the same standardization method. The criteria tree now looks like the one to the right.
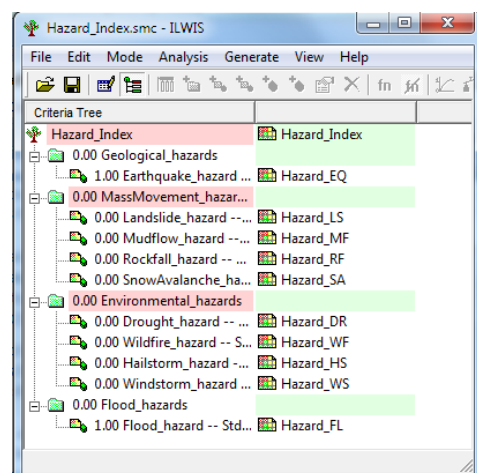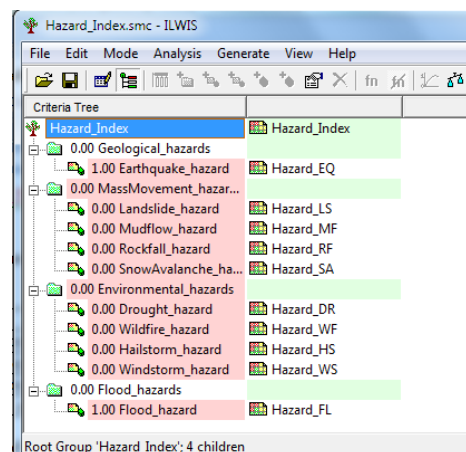
6.2.2 Determining the weights among factors

The third step in the procedure is to define the weights between the various factors. This can be between the factors in the same group (e.g. the two factors "Landslide_Hazard" and "Mudflow_hazard" in the group "MassMovement_hazards"), or the weights among the groups (e.g. "Flood_hazard" versus "Geological_hazard"). For the determination of weights SMCE use 3 different methods:

- **Direct weights** (you indicate the weights directly in a table),
- **Pairwise comparison** (you compare the factors in pairs, and based on the consistency of your selection and relative importance, quantitative values are given to the factors), See the example below left and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights). See the example below, right.
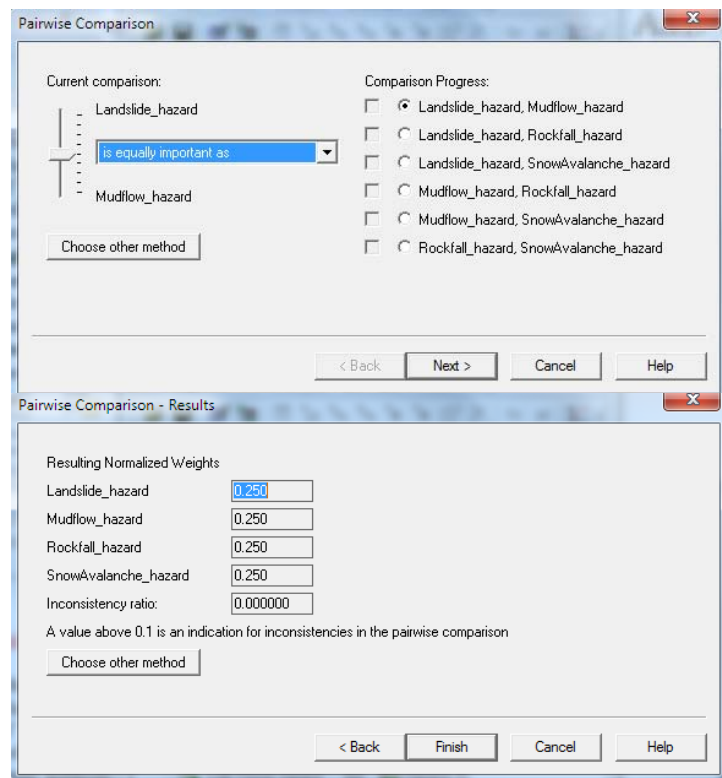
Weights

Weights are always numbers between 0 and 1. Weights cannot be negative. For the factors within a group, the sum of the weights of the factors equals 1. When a group only has one child, this child automatically obtains weight 1. Constraints are not considered during weighing.

- Right-click the red indicated factor group **"MassMovement_Hazard"**, and select Weight. Select the option: *Pairwise*

- Initially we are considering all of the hazards equally important. So go through the wizard and indicate for each pair that they are equally important.

- Generate also the weight for the group **Environmental_Hazards**. As the other two groups have only 1 indicator, we don't need to weight them. The result will look like the figure right.
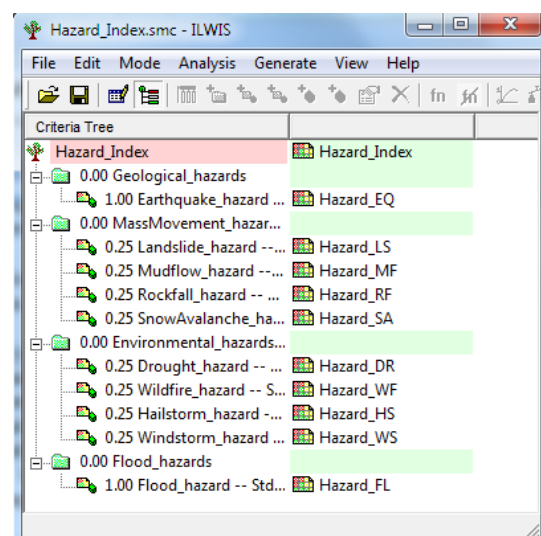
6.2.3 Determining the weights among groups

The fourth step in the procedure is to define the weights between among the groups (e.g. "Flood_Hazard" versus "MassMovement_hazard"). There are four groups in this example. Also here pair wise method could be used, but you might also try out another one.

- Right-click the red indicated upper line *"Hazard Index "*, and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance. Also give them the same weight.
- Save the criteria tree **Hazard_Index**
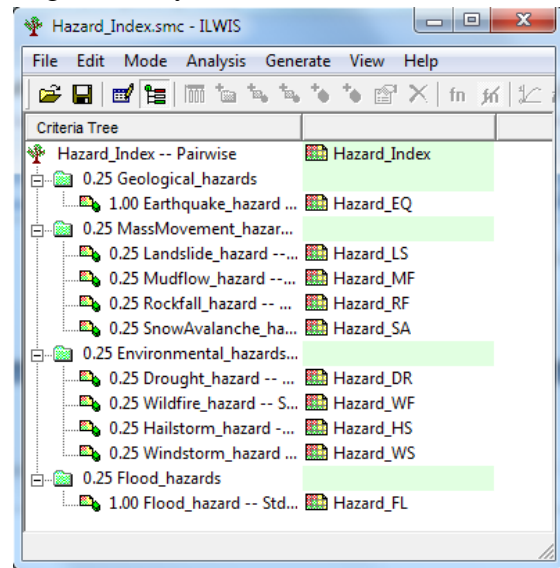
Now all the parameters are given and it is time to calculate the output map.

- Right-click the map icon "**Hazard_Index**", and select Generate selected item
- Display the result map. Use *PixelInfo* to compare the resulting map with the input maps.
- Question: What can you conclude from the pattern of different hazards?

6.2.4 Classify the result map in three classes

You can also classify the output map, or the intermediate hazard maps in a few classes. For that we will use a so-called Class/Group domain. Remember that all the result maps have values between 0 and 1.

- In the main window select *File/Create/ Domain* . In the domain window select the option **Class** and tick the option ▢**Group**. Name the file: Hazard_class, and click OK. Select Edit/Add item. Enter the values indicated below:

UpperBound	Name	Code
0.33	Low	L
0.66	Moderate	M
1.00	High	H

- Close the domain when you are reasy.

We now classify the value map (Hazard_Index) into a class map (Hazard_Index_Class) using the class/group domain (Hazard_class). The operation to do that is called Slicing.

- Go in the main window to *Operations, Image Processing, Slicing*. Select raster map: **Hazard_Index**, Output Raster map: **Hazard_Index_Class**, and domain: **Hazard_Class**
- Critically evaluate the result.

6.2.5 Evaluating alternative standardization and weighting method

In the method thus far we have given all the indicators and all the hazard types the same importance. This is of not rather questionable, because earthquakes cause a lot more damage than hailstorm for example, and shouldn't be given the same weights. Also for the final qualitative risk map it depends where we make the risk map for. If we do this for buildings, than earthquake hazard would obviously be the most important. But if we do this for agriculture, the environemental hazards will be more important. To see the effect of that you are now going to play with some alternatives and evaluate the effect of these.

- Open the Multicriteria tree **Hazard_Index**, and make sure the problem definition mode is selected (🖼️) . In menu, select Edit/Alternatives. In the window that is opened, select 3 alternatives. Name them: **EQual_weights, Focus_Buildings, Focus_agriculture** .

Alternative	Name	Idea
Equal_weight	Hazard_Index	We gave all hazards equal weights
Focus_buildings	Hazard_Index1	We evaluate the importance of the hazards for causing building damage
Focus_agriculture	Hazard_Index2	We evaluate the important of the hazards for causing damage to crops.

- Now weight maps again according to these ideas. Display the three resulting maps and compare them.
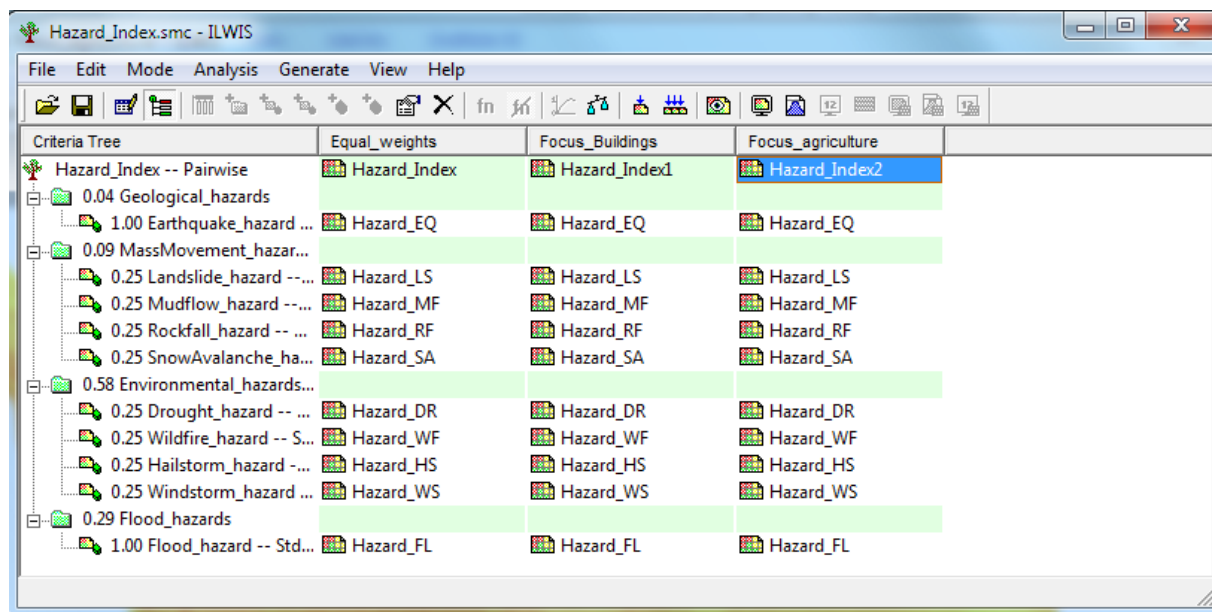
This shows that the weighting has a very large influence on the results and is also determined by the objective of the weighting.

7 GENERATING A BUILDING DATABASE USING EXISTING (BUT INCOMPLETE) CADASTRAL DATA.

Expected time: 3 hours
Data: **Exercise_Elements_at_Risk.zip**
Objectives: After this exercise you will be able to generate:
- A classification of buildings from incomplete cadastral data, into 3 occupancy types and 5 vulnerability types.
- Aggregate the building information per administrative unit in the country
- Generate building density maps.
- Analyze the problems involved when using existing data that is incomplete.

7.1.1 Introduction

In this exercise we will show how you can generate an elements-risk-database in a situation where existing data is available in the form of cadastral data. In Georgia cadastral data have been collected in a large project funded by the World Bank. The project didn't cover the entire country, so we can only use the available data for a part of the country, and for the other part we had to use data derived from satellite image interpretation.
Given the large size of the cadastral data we cannot do this exercise for the entire country, and we zoom in on an example from the Dedoplistskaro Municipality in the Kakheti Region in the Southeast part of Georgia (See figure 1)
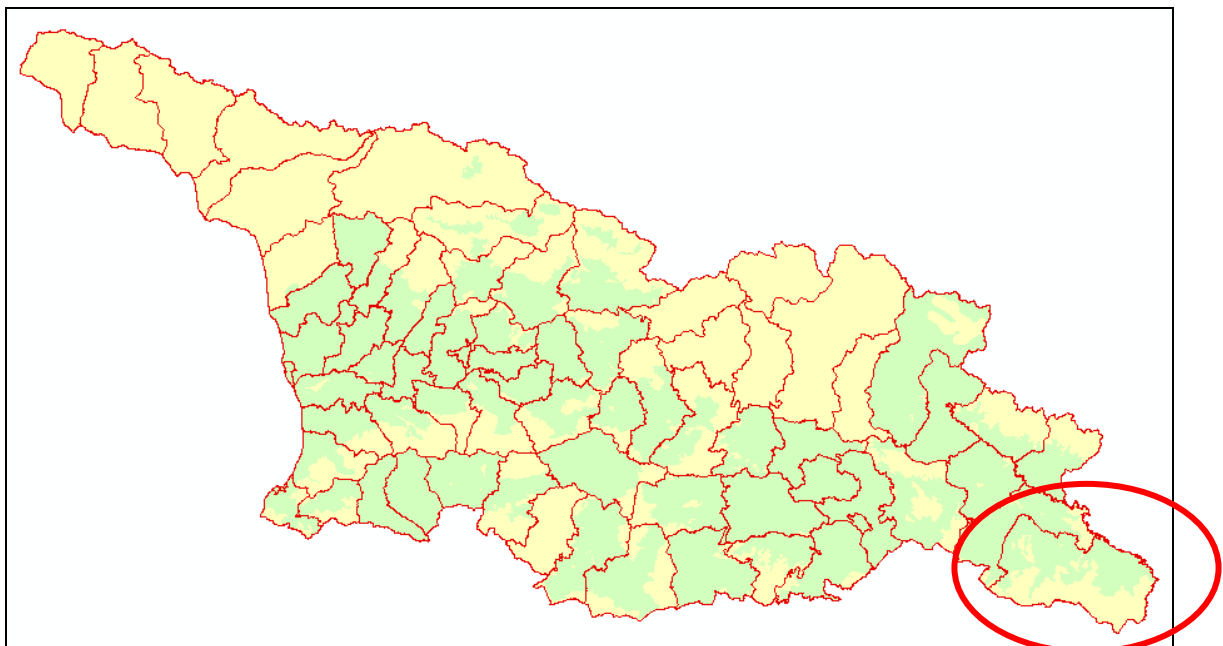
Figure 1. Area covererd by the cadastral database in Georgia (indicated in green). The red circle indicates the study area that is used in this exercise: Dedoplistskaro Municipality (Kakheti Region of Georgia).

7.1.2 Displaying the input data

For the exercise a number of input maps are available, for which the characteristics are given in the table below:

Map	Description
Land parcels	A Polygon map containing the land parcels from the cadastral database of Georgia.
Building_parcels	A Polygon map containing the building parcels from the cadastral database of Georgia
Dedoplistskaro	High resolution image downloaded from Google Earth with a spatial resolution of 2 meters.
Study_Area	This is a part of the national map containing all administrative units, such as communities, districts and regions. We will use this map to aggregate the building results.
Buildings_country	The final building map for the entire country, with statistical information on the number of buildings, for different occupancy classes and different vulnerability classes.
Building	A raster map showing the number of buildings per hectare in the country, made from cadastral data and from additional data in areas where no cadastral data was available.
Building_vulnerability	This is a script file which we will use later in the exercise to classify the buildings into different vulnerability classes.

We start by having a look at the image of the study area
- Open the raster map **Dedoplistskaro**
- Select: *Layers, Add Layers*, and add the polygon map **Building_parcels**.
- Zoom in and make an evaluation on the accuracy of the cadastral data, taking into account that the high resolution image is more recent than the building map. Question to be answered: If you had to make an estimation of the completeness of the building map, how much percentage would you estimate? Of course this is only in terms of the completeness of the building footprints, and not of the attributes of the buildings.

Your estimation of the completeness of the building_parcels is .... Percent

- Zoom in on a building and double click on it. The attribute window is opened.
- Check the meaning of the relevant attributes: **BuildingMaterial**, **BuildingPeriod** and **Nrfloors**. The column **ParcelID** is also important as this provides the key to the Land_parcel information.

Building Material		BuildingNo	
Code	Description	Code	Description
01	Wood	01	Main Building in the land parcel
02	Bricks	02	Second building in the land parcel (like kitchen, shed etc.)
03	Masonry	03	Third building
04	Concrete	04	Fourth building in the land parcel
05	Other		etc
Building period		**NrFloors**	
Code	Description	Code	Description
01	Pre_1950	1	1 floor
02	1950-1980	2	2 floors
03	Post_1980	3	3 floors

Table : Description of Building field codes (Building Material; Building/Construction Period; Number of floors, BuildingNo.). The column B_area contains the area of the building footprint in square meters.

We will now also add the map **Land_parcels.**

- Add the polygon map **Land_parcels**. In the *Display Options* window select: *Boundaries_Only* and choose a red colour.
- Zoom in on a land parcel and double-click on it. The attribute window is opened.
- Check the meaning of the relevant attributes: **LandUseType, Agricultural, P_Area**

The LandUseType has a number of classes, as indicated in the table below.

Code	Landuse type	Code	Landuse type	Code	Landuse type
0	Not Applied	23	Bridge	45	Lake
01	Residential	24	Surveyed by other projects	46	Channel
02	Industry	25	Road/Street	47	Bog
03	Service-Trade	26	Railway	48	Descent
04	Health	27	Cemetary	49	Pull
05	Education	28	Non-residential Building	50	River
06	Culture	29	Sculpture	51	Valley
07	Sport	30	Garage	52	Island
08	Police-Military	31	Square	53	Stones
09	Municipal	32	Reserve	54	Deep
10	Empty-Not Used	33	Sea coast	55	Meadow
11	Religious	34	Reserve	56	Rock
12	Mixed	35	Reserve	57	Reservoir
13	Park/Rest	36	Reserve	58	Private
14	Perineal Crops	37	Reserve	59	Lease
15	Arable	38	Reserve	60	Reserve
16	Pasture	39	Reserve	61	State Use
17	Forest	40	Reserve	62	State Ownership
18	Reservation	41	Bridge-Road	63	Mixed Ownership
19	Water Place	42	Bridge-Railway	64	Reserve
20	Communication	43	Bushes	99	Other
21	Boundary Zone	44	Windbreake line		

Table : Description of parcel field codes (Land types)

You can also show the various attributes in the map.

- Right-click in the *Map* window, and select: *Display_Options*, and select the *Polygon map* **Land_parcels**. In the *Display Options* window deselect: *Boundaries_Only* and select: *Attribute*. Select from the list the attribute: **LandUseType**, and also select the *Representation:* **LandUseType.** Click *OK*.
- Check the land use types in the map for the various land parcels and double click on it. The attributes window is opened.
- Display also attibute maps for other relevant attributes: **Agricultural.** *Representation*: **Agricultural.** Click *OK*.
- In the left pane of the *Map* window move the *Poygon map* **Building_parcels** up so that it is displayed on top of the **Land_parcels**. Also see how you can visualize the various attributes in the map **Building_parcels**.

- Zoom in and make an evaluation on the accuracy of the cadastral data, taking into account that the high resolution image is more recent than the building map. If you had to make an estimation of the completeness of the building map, how much percentage would you estimate? Of course this is only in terms of the completeness of the building footprints,. and not of the attributes of the buildings.

- Your estimation of the completeness of the land_parcels is .... Percent
- Give your estimation of the accuracy of the various attributes.
- Comment on the problems related to the use of such ancillary data for generating a good building map.

7.1.3 Summary of the problems involved in using the ancillary data.

It is obvious from looking at the data that the data base has a number of major problems, which are summarized below:
- The building map is outdated. Many new buildings have been constructed and old buildings have been demolished. This would require digitization of the new building footprints based on high resolution images.
- The land parcels map is also outdated. There are new developments in the area, and several large land use changes have taken place (e.g. the quarries in the north part of the city are not indicated). This also would require substantial digitization efforts.
- The attributes of the building parcels are not complete and are sometimes also questionable. For instance the column BuildingNo contains other codes for which we don't know the meaning). Many of the buildings have no information on Material Type, Building period, and number of floors. This will make it difficult to use them in a further analysis.
- The attributes of the Land_parcels are also problematic. The most important attribute (LandUseType) doesn't contain residential, and all residential plots are either labelled Arable or State_Ownership. So these are not the right attributes in order to make a good subdivision of the building types that can be used for building vulnerability assessment, and for population distribution modelling.

Of course a solution would be to survey the buildings again and collect the right attributes. However, where this is feasible for a small area, it is not possible to do for an entire country, and you would have to use this incomplete and inaccurate data as best as possible, making a number of assumptions. In the following part we will dea with these assumptions in order to make a building density and population density map from this.

7.1.4 Procedure for generating a building map

Step 1: Joining tables

As you can see we need some of the attributes that are linked to the **Land_parcels** in the table that links to the **Building_parcels**. We do this through the common key : **ParcelID**. Each cadastral parcel has a unique identifier, and if there are several buildings within the same land

parcel they share the same ParcelID. We are now going to join the two tables and brinf in all relevant columns into the table **Building_parcels**.

- Close the *Map window*, and open the *Table* **Building_parcels**.
- Select *Columns, Join…*, and the *Column Join* wizard opens. Select *Table*: **Land_parcels**, Select *Column*: **LandUseType**, Select: *Next, Next*. Select the key *Column*: **ParcelID**. Name the *Output column*: **LandUseType**.
- Do the same join operation and read-in the columns: **Agricultural** and **P_area**.

Now all relevant columns are together in the table **Building_parcels**.

We can now also calulcate how many buildings there are in each of the Land Use Types.

- In the *Table* **Building_parcels**
- Select *Columns, Aggregation*, and select *Column*: **LandUseType**, *Function*: **Count**, *Group by*: **LandUseType**, *Output Table*: **LandUseType**, *Output Column*: **Number_Buildings**.
- Open the table **LandUseType** and check how many building there are for each Land Use Type. Compare the results with the table below.

Code	Landuse type	Nr of parcels	Nr of Buildings	Occupancy Type	Conditions
0	Not Applied	0	0	Other buildings	
01	Residential	0	0	**Residential**	Nrfloor>=2 AND B-Area>=40
02	Industry	0	0	Administrative, social, business	
03	Service-Trade	6	6	Administrative, social, business	
04	Health	3	3	Administrative, social, business	
05	Education	0	0	Administrative, social, business	
06	Culture	0	0	Administrative, social, business	
07	Sport	0	0	Administrative, social, business	
08	Police-Military	0	0	Administrative, social, business	
09	Municipal	0	0	Administrative, social, business	
10	Empty-Not Used	0	0	Administrative, social, business	
11	Religious	0	0	Administrative, social, business	
12	Mixed	0	0	**Residential**	Nrfloor>=2 AND B-Area>=40
13	Park/Rest	22	5	Administrative, social, business	
14	Perineal Crops	931	881	**Residential**	Nrfloor>=2 AND B-Area>=40
15	Arable	38592	9400	**Residential**	Nrfloor>=2 AND B-Area>=40
16	Pasture	1443	156	**Residential**	Nrfloor>=2 AND B-Area>=40
17	Forest	341	1	Other buildings	
18	Reservation	34	2	Other buildings	
19	Water Place	1	1	Other buildings	
20	Communication	313	48	Other buildings	
23	Bridge	2	0	Other buildings	
25	Road	4237	2	Other buildings	
26	Railway	18	0	Other buildings	
27	Cemetary	3	0	Other buildings	
41	Bridge-Road	82	0	Other buildings	
42	Bridge-Railway	1	0	Other buildings	
43	Bushes	403	1	Other buildings	
44	Windbreake line	456	0	Other buildings	

45	Lake	24	0	Other buildings	
46	Channel	255	0	Other buildings	
47	Bog	14	0	Other buildings	
48	Descent	98	0	Other buildings	
49	Pull	4	0	Other buildings	
50	River	25	0	Other buildings	
55	Meadow	1465	25	Other buildings	
59	Lease	34	0	Administrative, social, business	
62	State Ownership	3395	2850	Administrative, social, business	

Table : Number of parcels and buildings per LandUseType, and proposed reclassification.

Step 2: Making assumptions

One of standard division of buildings by occupancy classes (land use) is provided in HAZUS (1. Residential; 2. Commercial; 3. Administrative; 4. Industrial; 5. Agriculture; 6. Religious; 7. Health-care; 8. Education).
Unfortunately, the incomplete data on the occupancy classes for the building stock does not allow us to make this subdivision, as we do not have the actual land use types of the buildings. We will have to make a number of assumptions. These are summarized in the table above. We are grouping the building into 3 main occupancy types:

Class	Description	LandUSeType (From table above)	Other conditions
A	Residential	1,12,14,15,16	Should be Main building in the plot (BuildingNo="01") Should have two floors or more (nrfloors>=2) Should have footprint area more than 40 m2 (B_area>40)
B	Administrative, social, business	2,3,4,5,6,7,8,9,10,11,13, 59, 62	None
C	Other buildings	All others.	None

Of course these assumptions are debatable, and could be inmproved. However, we will use these as these are the assumptions used by the Georgian group that prepared the building dataset for the national scale atlas. To implement these rules we follow the following steps.

- Open the *Domain* **Occupancy** and check the three classes. close it again.
- Open the *Table* **LandUseType** and type in the *Command line* the following equation:
$$Occupancy := \text{"Other\_Buildings"}$$
- Select ther *Domain*: **Occupancy** in the *Column Definition* window. Press *OK*.
- Select for each of the **LandUseTypes** the **Occupancy Class** according to the tables above.
- *Exit* the table when finished.

We will now read in this data into the table **Building_parcels**

- Open the *Table* **Building_Parcels**. Select: *Columns, Join...* In the *Table Join* **wizard,** select: *Table*: **LandUseType**, *Column*: **Occupancy**. *Next, Next, Finish.*
- Check now how each building has been reclassified into one of the three types.

As indicated in the table above we will make adjustments for the residential buildings as indicated above, based on the number of floors, floor area, and whether the building is the main one in the parcel.

- In the *Command line* of the *Table* **Building_Parcels** type carefull the following equation:

Occupancy_Class:=iff((Occupancy="A"),iff((BuildingNo="01") AND ((Nrfloors>= 2) OR (B_Area >= 40)),"A","C"),Occupancy)

A small explanation about this equation: We are using an IF statement, that has another If statement inside (nested IF statement). An IF statement has 3 components: IFF(condition, then, else). We can use in the equation the codes of the class names so that these result in shorter equations. When you make a class column less wide you see that the name is chaning to the code. So what we do in words is: if the occupancy class is "Residential_buildings (code="A"), then we check if it is the main building and wheter it either has more or eual than 23 floors or a floorspace of more than 40 meters. If that is the case, it remains a residential building, otherwise we change it to "Other_building" (Code="C"). For the other cases (meaning the Class B or Class C buildings) we do not change anything.

- Accept the default *Domain name*: **Occupancy**. After this: *OK.*
- Check in the table the differences between the two *Columns* **Occupancy** and **Occupancy_Class**
- Now we display the results in a map. First open the *Raster Map* **Dedoplistskaro**
- Select: *Layers, Add Layer…*, and add the *Polygon Map* **Building_parcels.** In the *Display Options* window, select *Attribute*: **Occupancy_Class,** select *Representation*: **Occupancy.** After this *OK*. Check the results.

We will now also make a column for each of the three occupancy classes, that contain a *1* if the buildings is of that class and a *0* if it is not.

- In the *Command line* of the *Table* **Building_parcels** type the following equations:
    A_Class:=iff(Occupancy_Class="A",1,0)
    B_Class:=iff(Occupancy_Class="B",1,0)
    C_Class:=iff(Occupancy_Class="C",1,0)
        Building:=1

This last equations makes a column with one (*1*) values so that you can easily see how many buildings there are in the study area. We will also use these columns later to aggregate the results into larger units for the national scale building map.

- Read from the statistics pace how many buildings there are in the study area, and how many buildings there are of Class_A, Class_B and Class_C.

7.1.5   Assigning vulnerability classes to the buildings

It is necessary to estimate building vulnerability conditions according to worldwide standards, one of such is the EMS 98 (European Macroseismic Scale 1998). It represents a rather schematic and simple way of assessment (see the table below) which is based on several major types of building structure and construction materials. The most difficult task is to fit existing, non engineering data, to the given classification, which itself is based on several simplifications.

Type of Structure		Vulnerability Class A B C D E F
MASONRY	rubble stone, fieldstone	
	adobe (earth brick)	
	simple stone	
	massive stone	
	unreinforced, with manufactured stone units	
	unreinforced, with RC floors	
	reinforced or confined	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	
	frame with moderate level of ERD	
	frame with high level of ERD	
	walls without ERD	
	walls with moderate level of ERD	
	walls with high level of ERD	
STEEL	steel structures	
WOOD	timber structures	

Table : Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table) according to EMS 98

The following table was constructed to assign vulnerability classes to buildings based on attributes:

TYPE	Stucture according to EMS98	Number of floors (NF)	Building Material (BM)	Building Period (BP)	Vulnerability Class (EMS98)
V1	**Timber Structures**				
		ANY	1	1	C
		ANY	1	2	D
		ANY	1	3	E
V2	**Masonry**				
	rubble stone, fieldstone	<=2	2	1	A
	simple stone	<=2	2	2 OR 3	B
	simple stone	3	2	1	B
	Unreinforced with RC floors	>=3	2	> 1	C
	Unreinforced with RC floors / Massive Stones	>=4	2	Any	C
V3	**Brick**				
	adobe (earth brick)	<=2	3	1	A
	unreinforced with manufactured stone units	>=3	3	1	B
	simple stone (brick)	<=2	3	2	B
	Unreinforced with RC floors	3	3	2	C
	Unreinforced with RC floors	<=3	3	3	C
	Unreinforced with RC floors	4,5	3	Any	C
	Frame without ERD	>=6	3	Any	C
V4	**Concrete**				
	frame/wall without ERD	Any	4	1	C
	frame/wall without ERD	<5	4	2	C
	frame/wall with moderate level of ERD	>=5	4	2	D
	frame/wall with high level of ERD	Any	4	3	E
V5	Other Materials				
	Other constructions	Any	5	1	A
	Other constructions	Any	5	2	B
	Other constructions	Any	5	3	C

Table 3: Decision matric for the classification of buildings into different vulnerabiklity classes, based on Number of Floors, Building Materials and Building (Construction) Period.

We can classify the buildings in the table **Building_Parcels** into one of these vulnerability classes, using a series of equations. The equations used to group the building in different vulnerability classes are indicated below:

V1:=iff(BM="01",iff(BP="01","C",iff(BP="02","D","E")),"O")
V2:=iff(BM="02",iff(NF<=2,iff(BP="01","A","B"),iff(NF=3,"B","C")),"O")
V3:=iff(BM="03",iff(NF<=3,iff(BP="01","A",iff(BP="02","B","C")),iff(BP="01","B","C")),"O")
v4:=iff(BM="04",iff(BP="01","C",iff(BP="02",Iff(NF<5,"C","D"),"E")),"O")
v5:=iff(BM="05",Iff(BP="01","A",Iff(BP="02","B","C")),"O")
Vulnerability:=iff(V1="O",iff(V2="O",Iff(V3="O",iff(V4="O",V5,V4),V3),V2),V1)
VA:=iff(Vulnerability="A",1,0)
VB:=iff(Vulnerability="B",1,0)
VC:=iff(Vulnerability="C",1,0)
VD:=iff(Vulnerability="D",1,0)
VE:=iff(Vulnerability="E",1,0)

- Try whether you can follow the reasoning behind the equations by comparing them with the decision matrix in the table above. This may be difficult.

We will not ask you to make these equations manually in the table Building_parcels, as this would be too difficult, and prone to writing mistakes. Therefore we have included these into a <u>script file</u>, which is a file in which you can store equations that can be executed automatically.

- Make sure to close the Table **Building_parcels**
- Open the *Script file* **Building_vulnerability** and check the contents. Compare it with the equations give above.
- In the script file press the *black triangle* ▶ to run the script. Alternatively you can also type on the *Command line* of the *Main* window:
                    Run building_vulnerability
- The script will need several minutes for the calculation. When it is completed, open the *Table* **Building_parcels** and check the results.

7.1.6 Aggregating the results of buildings for a national scale

After we have classified the individual buildings in the table **Building_Parcels** into occupancy and vulnerability classes, using a series of equations, we are now going to aggregate the results per communities, districts and regions so that the results can be used at a national scale. For this puroose we need a map containing the information on the communities, districts and regions. In our exercise we will use the map Study_Area.

- Open the *Map* **Study_Area**. *Double click* on one of the units, so that you can read the information in the attribute table. As you can see at the lowest level there are communities (some of which have no name), but each community has a unique **Community_ID**. One or more communities are grouped into **Districts** (Municipalities). And one or more municipalities into one **Region**. We are only looking here to one District: **Dedoplistskaro**.
- *Right-click* in the Map, and select the *Display options*. Now display several of the attributes in the map (Region, District, Communities). Use for the attributes the corresponding **Representation.**
- Also add as *Data Layer* the *Polygon Map* **Building_Parcels** over the displayed map, and use *PixelInfo* to read the results of the analysis you did before. Check also the columns in the *Table* **Building_parcels**, and check if it contains a *Column* **Study_area**, which contains the link between the codes used in the *Map* and in the *Table* **Study_area**, and the data in the *Table* **Building_parcels**.

We are now going to use aggregation function to write the total number of building per community into the table **Study_Area**, and also the number of building for each occupancy class and vulnerability class.

- Open the *Table* **Building_parcels**, and select *Columns, Aggregation….* Select: *Column:* **Building**, *Function*: **Sum**, *Group_By*: **Study_Area**, *Output Table*: **Study_Area**, *Output Column*: **Nr_Building**s.
- Repeat this for the other columns as well. See the table below for the names to use.

- When you complete, open the *Map* **Study_Area** again, and double click on any of the communities to read the summary information.

Column	Function	Group By	Output Table	Output Column
Building	Sum	Study_Area	Study_Area	Building
A_Class	Sum	Study_Area	Study_Area	A_Class
B_Class	Sum	Study_Area	Study_Area	B_Class
C_Class	Sum	Study_Area	Study_Area	C_Class
VA	Sum	Study_Area	Study_Area	VA
VB	Sum	Study_Area	Study_Area	VB
VC	Sum	Study_Area	Study_Area	VC
VD	Sum	Study_Area	Study_Area	VD
VE	Sum	Study_Area	Study_Area	VE

- To correct the values in the table that have undefined values (indicated as ?) which do not have buildings we need to make the following calculations in the *Command line*:

$$Nr\_Buildings:=iff(isundef(Building,0,Building$$
$$A\_Buildings:=iff(isundef(A\_Class,0,A\_Class)$$
$$B\_Buildings:=iff(isundef(B\_Class,0,B\_Class)$$
$$C\_Buildings:=iff(isundef(C\_Class,0,C\_Class)$$
$$VA\_Buildings:=iff(isundef(VA,0,VA)$$
$$VB\_Buildings:=iff(isundef(VB,0,VB)$$
$$VC\_Buildings:=iff(isundef(VA,0,VC)$$
$$VD\_Buildings:=iff(isundef(VA,0,VD)$$
$$VE\_Buildings:=iff(isundef(VA,0,VE)$$

- And finally, we want to calculate the percentage of the buildings for each class, you can do that with the following equations:

$$PA\_Building:=100*A\_Buildings/(A\_Buildings+B\_Buildings+C\_Buildings)$$
$$PB\_Building:=100*B\_Buildings/(A\_Buildings+B\_Buildings+C\_Buildings)$$
$$PC\_Building:=100*C\_Buildings/(A\_Buildings+B\_Buildings+C\_Buildings)$$
$$PVA\_Buildings:=100*VA\_Buildings/(VA\_Buildings+VB\_Buildings+VC\_Buildings+VD\_Buildings\_VE\_Buildings)$$
$$PVB\_Buildings:=100*VA\_Buildings/(VA\_Buildings+VB\_Buildings+VC\_Buildings+VD\_Buildings\_VE\_Buildings)$$
$$PVC\_Buildings:=100*VA\_Buildings/(VA\_Buildings+VB\_Buildings+VC\_Buildings+VD\_Buildings\_VE\_Buildings)$$
$$PVD\_Buildings:=100*VA\_Buildings/(VA\_Buildings+VB\_Buildings+VC\_Buildings+VD\_Buildings\_VE\_Buildings)$$
$$PVE\_Buildings:=100*VA\_Buildings/(VA\_Buildings+VB\_Buildings+VC\_Buildings+VD\_Buildings\_VE\_Buildings)$$

- To check the results, find the resulting values for the units indicated in the table below from the *Table* **Study_Area**, and write the numbers in the table below.

Community_ID	Community	Nr_Buildings	A_Buildings	B_Buildings	C_Buildings
1	Dedoplistskaro				
11	Zemo_Machkhaani				
3	Japaridze				

The same procedure was done for the entire country, at least for those areas where cadatral data was available. For the other areas we had do make a simplified procedure. There we used the national scale landuse map, in which built-up areas are one of the classes. From the areas where we do have cadastral data we calculated the number of buildings per hectare, and applied the same values to the units for which we didn't have building data.

- Open the *Map* **Buildings_Country**, and display them using *Boundaries Only*. when you doubl-click on any unit you can find the resulting values.
- Add the *Map* **Study_Area**
- Open **P***ixelInfo* and add the *Maps Study_Area* and *Buildings_Country*.
- Check whether there are any differences. The differences are caused by small differences in the input data for the exercise with respect to the data used initially for the entire country. However, the values are close.

7.1.7 Generating a Building Density map

Apart from using the aggregated building information per administrative unit, we also generated building density maps which display the number of buildings per pixel. In the study we are using a pixelsize of 1 hectare (100*100 meters). We do this by converting the building parcels into points and then rasterize the points in a grid of 1 hectare, where we count the number of points. We are using the same georeference (called Georgia) which defines the lower and upper coordinates (X and Y) and the pixelsize (100 meters).

- Open the *Gereference* **Georgia** to check the contents.

First we convert the polygon map **Building_Parcels** to points.
- Right click on the *Polygon map* **Building_parcels** and select *Vectorize, Polygons to Point*. Select: *Polygon_Map*: **Building_Parcels**, *Output Point Map*: **Building_parcels**.
- Display the Output map.
- Right click on the *Point map* **Building_Parcels**, and select *Vector Operations, Attribute Map*. Select Attribute: **Building**, Output Point Map: **Building**
- Display and check the output map.

Now we can rasterize the point based on attribute information.
- Right-click on the *Point map* **Building** and select *Rasterize,Point_Density*.
- Select: *Point Map*: **Building**, *Point Size:* **1**, *Output Raster Map*: **Building_Density**, *Georeference*: **Georgia**, *Domain*: **Value** , *Value Range*: 0 to 1000, *Precision*: 1.
- Display the output map, and overaly the *Polygon map* **Buildings_country** (In the *Display Options* window deselect the *INFO* option and select *Boundaries Only*). Zoom in on the study area and read the values from the **Building map**.

Of course the resulting map only has values for the study area. In the real case we should have the buildings points for the entire country. A similar procudere can be followed for making density maps for different occupancy classes (A, B or C) or different vulnerability classes (A to E). You can also compare your results with the overall building density map which was made for the country, called **Building**.

- Display the map **Building**, and use *PixeInfo* to compare this with your results .

8 GENERATING A VULNERABILITY INDEX USING SPATIAL MULTI CRITERIA EVALUATION.
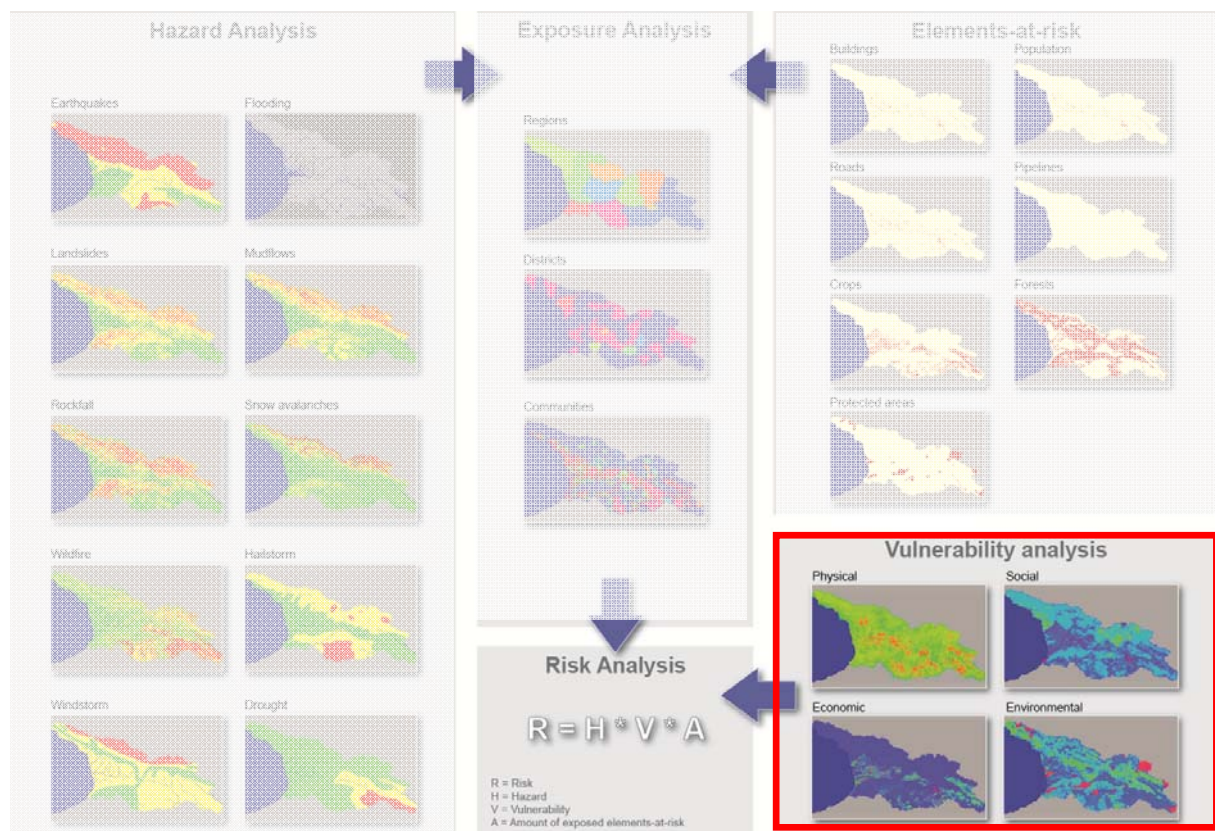
Expected time: 3 hours

Data: **Exercise_Vulnerability.zip**

Objectives: After this exercise you will be able to generate:

- A vulnerability index that combines the various elements at risk using a decision tree that has components for physical vulnerability, social vulnerability, economic vulnerability and environmental vulnerability. For each indicator in the decision tree you have to define the maps representing the factors, which have to be subsequently standardized and weighted. All procedures are based on Spatial Multi Criteria Evaluation

8.1   VULNERABILITY INPUT DATA

For the vulnerability assessment we need many more types of data, which are summarized in the table below.

Vul	Map	Type	Description
Physical	Building_dens	Building_density	Number of buidlings per hectare calculated from cadastral data and from landuse data.
	Community_buildings		Column: A Buildings: residential buildings Column: B Building: offices, shops schools etc Column: C Building: Building with hadly any population in it. Columns: VA to VE buildings. Number of buildings with vulnerability classes from high to low. Columns: PVA to PVE. PErcentage of buildings with vulnerability classes from high to low.
	Airport	Airport map	Location of airports and types
	Railroad	Railroad	Location and importance of railroads
	Road_hgihway	Length of highway	Length of highways per hectare
	Road_streets	Length of roads	Length of paved roads per hectare
	Road_unpaved	Length of unpaved roads	Length of unpaved roads per hectare.
	Electric_line	Electric power lines	Location of electric power lines
	Power_stations	Electric power stations	Location of Electric power stations
	E-Substations	Electric substations	Location of electric substations
	Fire_stations_distane	Distance to fire station	Distance to the nearest fire station calculated along the road.
Social	Population	Number of people	Number of people per hectare, generated from cadastral and population data.
	Medical_distance	Distance to hospital	The distance to the nearest hospital calculated along the roads with different weights per road type.
	Community_population :	Large table with population information per community	Column: population density Column: % hospital beds Column: % doctors Column: % of children per administrative unit Column: % of teachers per administrative unit
	School_distance	Distance to the nearest school	Distance to the nearest school calculated from the school point map, and using the road network.
	Perc_disable	Disabaled people	Percentage of people per hectare that are disabled/handicapped
	Perc_socially_un	Socially insecure groups	Percentage of people per hectare that are poor
Environmental	Protected zones	National parks	Protected zones, national parks etc.
	Cultural_heritage sites	Cultural heritage	Mapping of cultural heritage sites, like old churches, fortreses etc.
	Rivers_lakes	Waterbodies and closeness to urban areas	Map of lakes and rivers that are within 11 kilometres from urban areas
	Geomorphology_Georgian	Landscape uniqueness	REclassification of the Geomorphological map base don the uniqueness of the geomorphological features.
	Landcover_simple	Landcover types like forests and wetlands	Simplified land cover map with information on forests and wetlands
Economic	AgricultureGDP ForestryGDP EducationalGDP ServicesGDP TourismGDP	Gross Domestic Product for different sectors	This information was obtained by first generating a GDP map which was available for administrative units, and calculating the GDP per pixel for different landuse types, based on a landuse map. They are used for generating the economic vulnerability map

- If you are interested to know more about how the baseline maps have been made, you can read Chapter 2 of the Risk Atlas. The description of the vulnerability you can find in chapter 5 of the atlas
- In ILWIS, open the various maps indicated in the table above, and check their content.
- Also use PixelInformation ( ).

We will come back why these maps were used in the vulnerability assessment later on in this exercise.

8.2   CREATING THE CRITERIA TREE FOR THE VULNERABILITY INDEX

You can also generate the criteria tree for the vulnerability index. Vulnerability is the most complicated component of risk assessment, because the concept of vulnerability has a wide range of interpretations. Multiple definitions and different conceptual frameworks of vulnerability exist. Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. It is the susceptibility to suffer damages or the intrinsic fragility of exposed elements, systems or communities that favours loss when affected by hazard events. It includes also the lack of resilience that influence the capacity to anticipate, cope with, resist, respond to, and recover from the impact of a physical event (www.move-fp7.eu/

The vulnerability of communities can be analyzed in a holistic qualitative manner using a large number of criteria that characterize the physical, social, economic and environmental vulnerability. The importance of each of these indicators is evaluated by assigning weights and combining them using spatial multi-criteria evaluation. Physical vulnerability is evaluated as the interaction between the intensity of the hazard and the type of element-at-risk, making use of so-called vulnerability curves. Vulnerability is multi-dimensional (physical, social, economic, environmental, institutional, and human factors define vulnerability), dynamic (it changes over time), scale-dependent (it can be expressed at different scales from individuals to countries), and site-specific (each location might need its own approach).

The criteria tree for the vulnerability index is much more complicated than the one for the hazard index. We therefore have reated the tree already for you. The tree is called **Vulnerability_index**.

- Open the criteria tree **Vulnerability_index**. As you can see we have already made the tree for your and indicated the groups and subgroups. We didn't make the links with the maps however.

We grouped the vulnerability into four major types:
- Physical vulnerability: in which we looked at the vulnerability of buildings, transportation infrastructure, lifelines and essential facilities.
- Social vulnerability: in which we evaluated the vulnerability of population based on their density
- Environmental vulnerability: combining information on cultural heritage, protected areas, geomorphologically important areas and waterbodies
- Economic vulnerability: combining information on Gross Domestic Products for different sectors

The large criteria tree is indicated in the following page.

Vulnerability.smc - ILWIS

File   Edit   Mode   Analysis   Generate   View   Help

Criteria Tree

Criteria Tree	
Vulnerability -- Pairwise	Vuln_overall
0.37 Physical_Vulnerability -- Pairwise	Vuln_Physical
0.53 Building_vulnerability -- Pairwise	Vuln_Building
0.26 Building_density	
1.00 Building_density -- Std:Attr='Importance'	Building_dens
0.10 Building_types -- Pairwise	
0.75 Residential -- Std:Concave(0.000,13365.000)	Community_Buildings_New:A_Buildings
0.18 Offices -- Std:Concave(0.000,22635.000)	Community_Buildings_New:B_Buildings
0.06 Others -- Std:Concave(0.000,25136.000)	Community_Buildings_New:C_Buildings
0.64 Building_vuln_class -- Pairwise	
0.50 Absolute number -- Pairwise	
0.51 Vulnerability_A -- Std:Concave(0.000,6575.000)	Community_Buildings_New:VA_Buildings
0.26 Vulnerability_B -- Std:Concave(0.000,1857.000)	Community_Buildings_New:VB_Buildings
0.13 Vulnerability_C -- Std:Maximum	Community_Buildings_New:VC_Buildings
0.06 Vulnerability_D -- Std:Convex(0.000,41067.000)	Community_Buildings_New:VE_Buildings
0.03 Vulnerability_E -- Std:Convex(0.000,41067.000)	Community_Buildings_New:VE_Buildings
0.50 Percentatges -- Pairwise	
0.51 Vulnerability_A -- Std:Goal(0.000,1.000)	Community_Buildings_New:PVA_Buildings
0.26 Vulnerability_B -- Std:Maximum	Community_Buildings_New:PVB_Buildings
0.13 Vulnerability_C -- Std:Maximum	Community_Buildings_New:PVC_Buildings
0.06 Vulnerability_D -- Std:Maximum	Community_Buildings_New:PVD_Buildings
0.03 Vulnerability_E -- Std:Maximum	Community_Buildings_New:PVE_Buildings
0.11 Transportation -- Pairwise	Vuln_Transport
0.14 Airport_vulnerability	
1.00 airports -- Std:Attr='Importance'	Airport
0.43 Railroad_vulnerability	
1.00 Railroads -- Std:Attr='Importance'	Rail_road
0.43 Road_Vulnerability -- Pairwise	
0.77 Highways -- Std:Concave(0.000,625.000)	Road_Highway
0.17 Streets -- Std:Concave(0.000,617.000)	Road_streets
0.05 Unpaved_roads -- Std:Concave(0.000,457.000)	Road_Unpaved
0.16 Lifelines	Vuln_Lifelines
1.00 Electrical_power -- Direct	
0.50 Power_lines -- Std:Attr='Importance'	Electric_line
0.30 Power_plants -- Std:Attr='Importance'	Power_station_type
0.20 Power_substations -- Std:Attr='importance'	E_substations
0.21 Essential_facilities -- Direct	Vuln_Essential
0.60 Distance to Medical_facilities -- Std:Concave(0.000,433...	Medical_distance
0.40 Distance to Fire_brigades -- Std:Concave(0.000,434012....	Fires_station_distance
0.37 Social_vulnerability -- Direct	Vuln_Social
0.50 Population_density -- Pairwise	Population_comp
0.88 Density_pixel -- Std:Concave(0.000,887.000)	population
0.13 Density_commune -- Std:Concave(0.000,3229.000)	Community_population:Population_density
0.20 Healthcare -- Direct	Vuln_Healthcare
0.33 Distance_hospital -- Std:Concave(0.000,433722.094)	Medical_distance
0.33 Nr_hospital_beds -- Std:Convex(-0.068,51.720)	Community_population:N_bedsPer1000
0.33 NR_medical_staff -- Std:Convex(0.000,100.000)	Community_population:N_medicalPer100
0.15 Education -- Direct	Vuln_Education
0.33 Nr_school_children -- Std:Goal(0.000,0.690)	Community_population:PercChildren
0.33 Nr_teachers -- Std:Goal(0.000,0.810)	Community_population:PercTEachers
0.33 Distance_to_school -- Std:Concave(0.000,433451.000)	SChool_distance
0.15 Disadvantaged_groups -- Pairwise	Vuln_groups
0.10 Environmental_Vulnerability -- Pairwise	Vuln_Environ
0.23 National_parks -- Std:Attr='Importance'	Protected_zones
0.48 Cultural_heritage -- Std:Attr='Importance'	Cultural_heritage_sites
0.14 Waterbodies -- Std:Attr='Importance'	Rivers_lakes
0.06 Landscape -- Std:Attr='Importance'	Geomorphology_georgian
0.09 Landcover -- Std:Attr='Importance'	LandcoverSimple
0.17 Economic_vulnerability -- Pairwise	Vuln_Economic
0.11 Agricultural_sector -- Std:Concave(0.000,1062730.000)	AgricultureGDP
0.07 Forestry_sector -- Std:Goal(0.000,981.250)	ForestryGDP
0.15 Tourism_sector -- Std:Goal(0.000,3854.550)	TourismGDP
0.10 Educational_sector -- Std:Goal(0.000,3854.550)	EducationalGDP
0.28 IndustryGDP -- Std:Goal(0.000,10000.133)	IndustryGDP
0.28 ServicesGDP -- Std:Goal(0.000,10000.000)	ServicesGDP

Root Group 'Vulnerability'; 4 children

The criteria tree is indicated schematically in the figure below. It consists of the main groups (the four vulnerability types), the subgroups, and the indicators. Also the weights used are indicated.

Main groups	Sub-groups, level 1	Sub-groups, level 2	Indicators
Physical vulnerability (0.37)	Building vulnerability (0.53)	Building Density (0.26)	Building density (1.00)
		Building Types (0.10)	Nr buildings Type A (0.75)
			Nr buildings Type B (0.18)
			Nr buildings Type C (0.06)
		Building vulnerability types (0.64)	Nr buildings Type A (0.51)
			Nr buildings Type B (0.26)
			Nr buildings Type C (0.13)
			Nr buildings Type D (0.06)
			Nr buildings Type E (0.03)
	Transportation vulnerability (0.11)	Airport vulnerability (0.14)	Airports (1.00)
		Railroad vulnerability (0.43)	Railroads (1.00)
		Road vulnerability (0.43)	Highway density (0.77)
			Paved road density (0.17)
			Unpaved road density (0.05)
	Lifelines (0.16)	Electrical power (0.50)	Power lines (0.50)
			Power plants (0.30)
			Sub stations (0.20)
		Water supply (0.50)	Water supply (1.00)
	Essential facilities (0.21)	Medical centers (0.60)	Distance to medical center (1.00)
		Fire-brigades (0.40)	Distance to fire brigades (1.00)
Social Vulnerability (0.37)	Population density (0.50)		Per hectare (0.87)
			Per community (0.13)
	Healthcare (0.20)		Distance to hospitals (0.33)
			Nr of hospital beds (0.33)
			Nr of doctors (0.33)
	Education (0.15)		Nr school children (0.33)
			Nr teachers (0.33)
			Distance to schools (0.33)
	Disadvantaged groups (0.15)		Disabled persons (0.50)
			Socially unsecured (0.50)
Environmental vulnerability (0.10)			National parks (0.23)
			Cultural heritage (0.48)
			Waterbodies and closeness to urban areas (0.14)
			Landscape uniqueness (0.06)
			Landcover types like forests and wetlands (0.09)
Economic vulnerability (0.17)			Agricultural sector (0.11)
			Forestry sector (0.07)
			Tourism sector (0.15)
			Educational sector (0.10)
			Industry (0.28)
			Services (0.28)

8.2.1   Physical vulnerability

Physical vulnerability is the potential for physical impact on the built environment and population. It is defined as the degree of loss to a given element-at-risk or set of elements-at-risk resulting from the occurrence of a natural phenomenon of a given magnitude, and expressed on a scale from 0 (no damage) to 1 (total damage). PhysicaL vulnerability is related to the characteristics of the elements-at-risk, and to the hazard intensity. Physical vulnerability as such is therefore not a spatial component, but is determined by the spatial overlay of exposed elements-at-risk and hazard footprints.

In this study we used the following main groups of indicators for assessing the physical vulnerability: Building vulnerability, Transportation vulnerability, Lifeline vulnerability, and the vulnerability of Essential facilities.

Building vulnerability assessment

In order to be able to analyze the building vulnerability we needed to collect information on the location of built-up areas, the number of buildings per administrative unit, the average building size and the typology of buildings. In our analysis we used three building related indicators to derive the building vulnerability map: building density, building type and building vulnerability classes.

In section 3.2.4 of the risk atlas the methods for generating the building density information, and building types were explained. To estimate building vulnerability conditions according to acting worldwide standards, we followed the method presented in the European Macroseismic Scale (EMS 98). It is a relatively simple way of assessment that subdivides buildings into 5 vulnerability classes, mainly on the basis of several major types of building structure and material. It was problematic to fit existing non engineering data to the given classification, which itself is based on several simplifications and expert knowledge of existing pro and post soviet building stock in Georgia.

Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table) according to EMS 98

The following table was constructed to assign vulnerability classes to buildings based on several attributes related to building structure, number of floors, materials, and period of construction.

Classification of buildings into 5 vulnerability classes

TYPE	Stucture according to EMS98	floors	Material	Period	Vulnerability Class (EMS98)
1	**Timber Structures**	ANY	1	1	C
		ANY	1	2	D
		ANY	1	3	E
2	**Masonry**				
	rubble stone, fieldstone	<=2	2	1	A
	simple stone	<=2	2	2 OR 3	B
	simple stone	3	2	1	B
	Unreinforced with RC floors	>=3	2	> 1	C
	Unreinforced with RC floors / Massive Stones	>=4	2	Any	C
3	**Brick**				
	adobe (earth brick)	<=2	3	1	A
	unreinforced with manufactured stone units	>=3	3	1	B
	simple stone (brick)	<=2	3	2	B
	Unreinforced with RC floors	3	3	2	C
	Unreinforced with RC floors	<=3	3	3	C
	Unreinforced with RC floors	4,5	3	Any	C
	Frame without ERD	>=6	3	Any	C
4	**Concrete**				
	frame/wall without ERD	Any	4	1	C
	frame/wall without ERD	<5	4	2	C
	frame/wall with moderate level of ERD	>=5	4	2	D
	frame/wall with high level of ERD	Any	4	3	E

The building density, building types and building vulnerability classes were weighted using a pairwise method and combined into a final qualitative building vulnerability map.

- In the criteria tree **Vulnerability_index,** standardize the relevant input maps using the information from the example criteria tree.

How to standardize?
You have to define yourself the ranges between you standardize. Consider for each factor: how much should the value be in order to consider it very vulnerable? For instance: how large should the percentage elderly people per mapping unit be to give it a 1 value (highly vulnerable). These threshold values are often defined in a group decision making process:
- **Maximum**: The input values are divided by the maximum value of the map;
- **Interval**: Linear function with the maximum and minimum values of the map;
- **Goal**: Linear function with specified maximum and minimum values;
- **Piecewise linear**: Linear function with two breaking points located between the extremes
- **Convex**: Convex function with one user defined value to re-shape the curve;
- **Concave**: Concave function with one user defined value to re-shape the curve;

- **U-Shape**: U-shape curve with one user defined value to stretch or shrink the curve GaussianBell-shape curve with one user defined value to stretch or shrink the curve.

You have the option to select several ways of scaling the values between 0 and 1. The figure below shows the standardization window, and the various options.

When selecting the boundaries for standardization, you always have to consider the aim of the weighting and standardization procedure (in this case social vulnerability), and how this particular variable is related to that. In this case: the higher the percentage of children in an area, the higher the vulnerability of the population. In that case you can use a simple straight line, between 0 and the maximum value. In other cases there will be a maximum value above which you will always find it high. E.g. for the estimation of the population losses, you could say that anything above 20 is high, and should be 1. In that case you select the Goal option, and you can adjust the values manually.
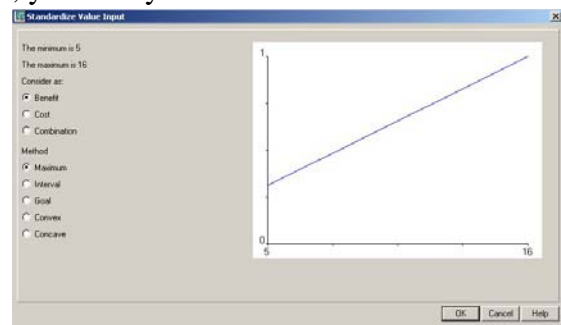
- In the criteria tree **Vulnerability_index,** standardize the indicators using the information from the example criteria tree.
- Weight the indicators in the sub=groups.
- Create the intermedite map: **Vuln_building** and check the results

Transportation vulnerability assessment

Transportation vulnerability assessment was carried out by weighting the importance of airports (international, and local), railroad types, and road types. Three density maps of roads were made for highways, paved roads and unpaved roads, expressing the length of these per hectare. These were then combined into a road vulnerability indicator using the following weights: Highway density (0.77), Paved road density (0.17), and Unpaved road density (0.05). The weights for different transportations types were: Airport vulnerability (0.14), Railroad vulnerability (0.43), Road vulnerability (0.43). The railroad system in Georgia is considered equally important as the road system for transporting goods from the harbours inland.

- In the criteria tree **Vulnerability_index,** standardize and weight theindicators using the example.
- Create the intermedite map: **Vuln_transport** and check the results

Lifeline vulnerability

Lifelines are those networks that provide basic services to the population, such as water supply, electricity supply, gas supply, telecommunications, mobile telephone network, and sewage system. Unfortunately we didn't have access to digital data on each of these network, so we used only two major components: Electrical power and Water supply , which were considered equally important in the weighting process. For the electrical power supply we collected information on power lines (normalized according to their capacity and weighted as 0.50), electrical power plants (normalized according to their capacity and weighted as 0.30), and electrical sub stations (weighted as 0.20).

- In the criteria tree **Vulnerability_index,** standardize and weight theindicators using the example.

- Create the intermedite map: **Vuln_lifelines** and check the results
-

Essential facilities.
Essential facilities are those facilities that provide services to the community and should be functional after a disaster event. Essential facilities include hospitals, police stations, fire stations and schools. In our analysis we have used information on the medical centers (hospitals, weighted as 0.60) and fire stations (weighted as 0.40). For both of these we calculated the distance to them following the road network, using a special GIS operation. The four sub-maps related to physical vulnerability were combined in the following way: Building vulnerability (0.53), Transportation vulnerability (0.11), Lifelines (0.16) and Essential facilities (0.21).

- In the criteria tree **Vulnerability_index,** standardize and weight theindicators using the example.
- Create the intermedite map: **Vuln_essential** and check the results
- Now you can also create the intermedite map: **Vuln_physical** which combines the buldingvulnerability, tranport vulnerability, lifeline vulnerability and essential facilities vulnerability and check the results

8.2.2 Social vulnerability

Social vulnerability is the potential impact of events on groups within the society (such as the poor, single parent households, pregnant or lactating women, the handicapped, children, and elderly), and it considers public awareness of risk, ability of groups to self-cope with catastrophes, and the status of institutional structures designed to help them cope.
In the analysis of the social vulnerability we have used the following indicator groups:

- Population density (0.50). The population density was expressed in two ways: per hectare using a dasymetric mapping approach based on the building map combined with population statistics per community. This was weighted as 0.87. The other sources was the population per community, which was weighted as 0.13. This was done as the building map doesn't cover all individual buildings in the rural part of the country.
- Healthcare (0.20). The healthcare subgroup was subdivided into a number of indicators:
  - Distance to hospitals (0.33) was calculated following the road network using a special GIS operation.
  - The number of hospital beds (0.33) was obtained from a database at the community level, and was recalculated per 10000 persons.
  - The number of doctors (0.33) was also available per community, and was recalculated per 10000 persons
- Education (0.15). Three indicators were used to characterize this subgroup:
  - The number of school children (0.33) was available per administrative unit.
  - The number of teachers (0.33) was also available per administrative unit.
  - Distance to schools (0.33) was calculated following the road network.
- Disadvantaged groups (0.15). For this subgroup only two indicators could be obtained:
  - The number of Disabled persons (0.50) per administrative unit

o The number of socially unsecured (0.50) people per administrative unit.

Tasks:

- In the criteria tree **Vulnerability_index,** standardize and weight theindicators using the example.
- Create the intermedite map: **Vuln_essential** and check the results
- Now you can also create the intermedite map: **Vuln_social** which combines the dfferent socil vulnerability groups and check the results

8.2.3 Economic and Environmental vulnerability

Economic vulnerability is defined as the potential impact of hazards on economic assets and processes (i.e., business interruption, secondary effects such as increased poverty and job loss). Environmental vulnerability evaluates the potential impacts of events on the environment (flora, fauna, ecosystems, biodiversity).
For analyzing the environmental vulnerability we have taken into account the following indicators:
- National parks (weighted 0.23. The individual natural parks were not weighted separately, and all of them were considered equally important.
- Cultural heritage (weighted 0.48). Cultural heritage sites were given the highest weight due to the fact that they are irreplaceable, whereas ecological zones might still regenerate after the impact of a disaster event.
- Waterbodies and closeness to urban areas (0.14). This was considered as the vicinity of waterbodies to urban areas might lead to pollution problems. A distance buffer of 11 kilometers was used and subdivision was made between lakes and reservoirs.
- Landscape uniqueness (Weighted 0.06). This was obtained from the map of Geomorphology and the various landscapes were evaluated based on their landscape values and characterized with a value between 0 and 1.
- Landcover types like forests and wetlands (Weighted 0.09). The landuse map was used to differentiate the forest and wetlands in the country.

For analyzing the economic vulnerability we have taken into account the following indicators:
- Agricultural sector (0.11). The agricultural production was obtained for each district and the total value was divided over the areas indicated as crops in the landuse maps. The values were normalized using the maximum value.
- Forestry sector (0.07). The forestry production was obtained for each district and the total value was divided over the areas indicated as forests in the landuse maps. The values were normalized using the maximum value.
- Tourism sector (0.15). Information on the tourism sector was obtained from digital information on the location of hotels, and tourist resorts.
- Educational sector (0.10). Point information on the schools and their typology was used to weight the schools.
- Industry (0.28). The location of the main industrial areas was obtained from several digital maps and the importance of the industrial zones was taken into account in the weighting.

- Services (0.28). For the estimation of the importance of services (commercial businesses etc.) we used information from several sources, and GDP information for administrative units.

Tasks:

- In the criteria tree **Vulnerability_index,** standardize and weight theindicators using the example.
- Create the intermedite map: **Vuln_environmental** and **vuln_economic** and check the results

8.2.4 Overall vulnerability

The vulnerability indicators, defining the physical, economic, social and environmental vulnerability can be aggregated and combined into an overall vulnerability map using Spatial Multi-Criteria Evaluation. In the analysis we have used the following weights:

- Physical vulnerability (0.37)
- Social Vulnerability (0.37)
- Environmental vulnerability (0.10)
- Economic vulnerability (0.17)

Physical and social vulnerability were considered equally important and both more important than economic vulnerability. Environmental vulnerability was given the lowest scores. The map of the final vulnerability shows a clear pattern, where the main urban areas are having the highest values as they both score high on the physical and social vulnerability. The table shows the entire criteria tree used in the vulnerability assessment.

Tasks:

- In the criteria tree **Vulnerability_index,** standardize and weight the indicator groups using the example.
- Create the intermedite map: **Vuln_overall** and check the results

8.2.5 Classify the resulting vulnerability map in three classes

You can also classify the output map, or the intermediate hazard maps in a few classes. For that we will use a so-called Class/Group domain. Remember that all the result maps have values between 0 and 1.

- In the main window select *File/Create/ Domain* . In the domain window select the option **Class** and tick the option □**Group**. Name the file: **Vulnerability_class**, and click OK. Select Edit/Add item. Enter the values indicated below:

UpperBound	Name	Code
0.33	Low	L
0.66	Moderate	M
1.00	High	H

- Close the domain when you are reasy.

We now classify the value map (**Vuln_Overall**) into a class map (**Vulnerability_Index_Class**) using the class/group domain (**Vulnerability_class**). The operation to do that is called Slicing.

- Go in the main window to *Operations, Image Processing, Slicing*. Select raster map: **Vuln_overall**, Output Raster map: **Vulnerability_Index_Class**, and domain: **Vulnerability_Class**

- Critically evaluate the result.

8.3 COMBINATION OF THE HAZARD INDEX AND THE VULNERABILITY INDEX INTO A QUALITATIVE RISK INDEX,

The final step of the exercise is to create a qualitative risk map by combining the maps: Hazard_Index_Class and Vulnerability_Index_Class. We will do this with a so-called two-dimensional table.

- In the main window select *File/Create/ 2 Dimensional Table* . In the window select the table name: **Qualitative_risk_table**, select the primary domain: **Hazard_Class**, select the secondary domain: **Vulnerability_Class**. Select the domain: **Qualitative risk**.

The following table will now open

- Select the combinations of vulnerability and hazard so that high vulnerability and hazard result in high risk etc,

The result will look like the one below.

Once the two dimensional table is made we can combine the Hazard_Index_Class and the Vulnerability_Index_Class maps using the following statement.

	Low	Moderate	High
Low	?	?	?
Moderate	?	?	?
High	?	?	?

	Low	Moderate	High
Low	Low	Low	Low
Moderate	Low	Moderate	Moderate
High	Low	Moderate	High

- In the command line of the main window write the following formula: **Qualitative_risk:= Qualitative_Risk_Table[Hazard_Index_Class, Vulnerability_Index_Class]**

- Display the resulting map **Qualitative_risk** and check the contents with PixelInfo adding the maps **Hazard_Index_Class** and **Vulnerability_Index_Class,** and the other input maps that were used to generate these.
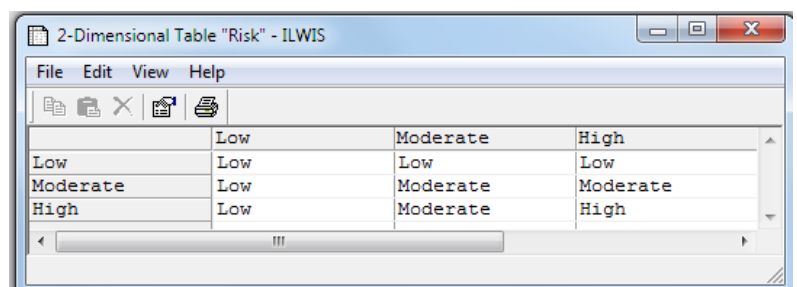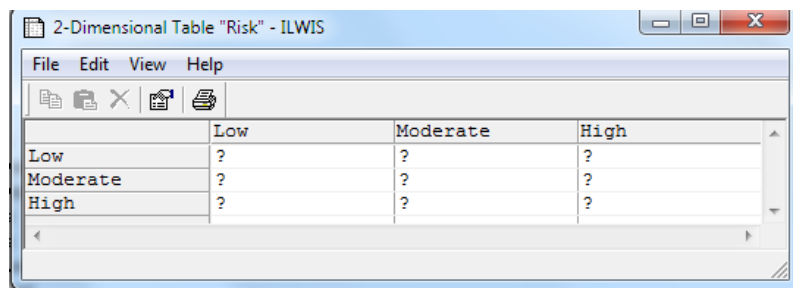
9 CALCULATING EXPOSURE INFORMATION FOR MULTI-HAZARDS AND DIFFERENT ELEMENTS-AT-RISK.
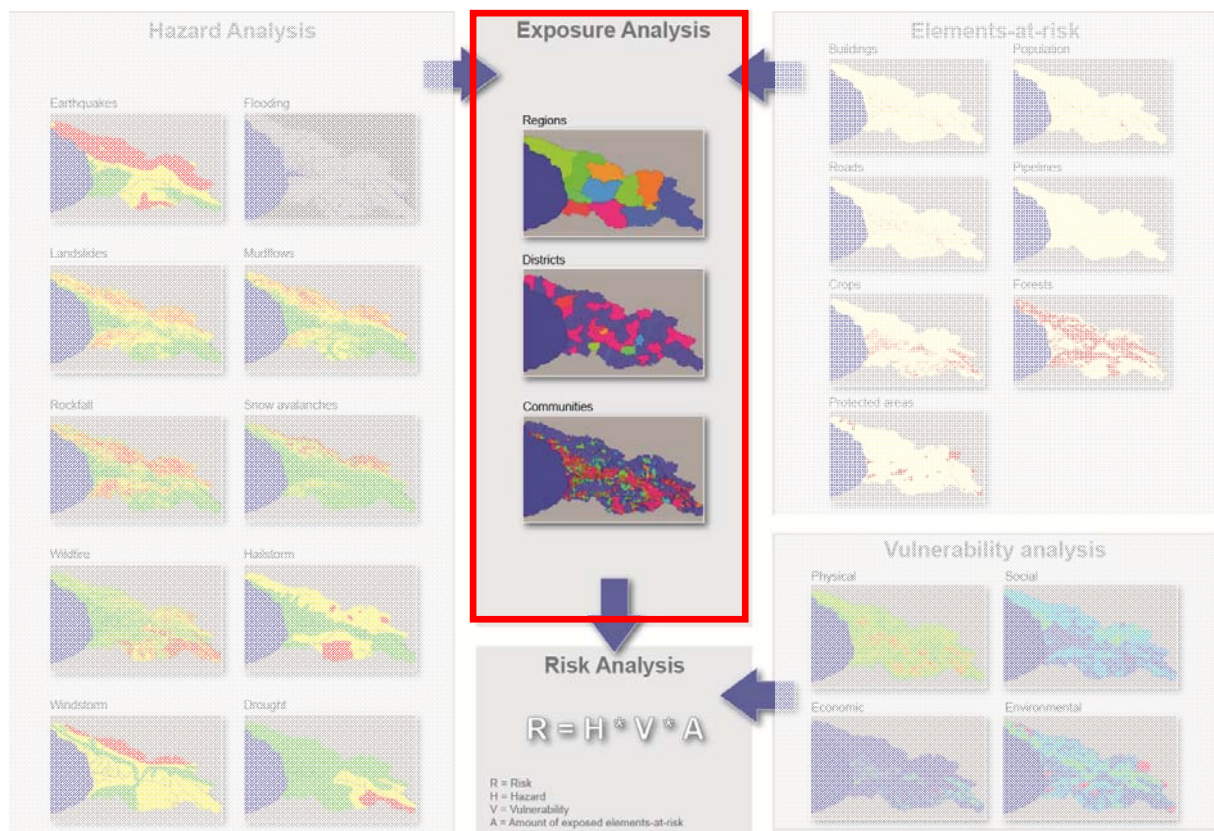
Expected time: 3 hours

Data: **Exercise_Exposure.zip**

Objectives: After this exercise you will be able to generate:

- Exposure information related to three individual components:
- Hazard maps: you can select one or more hazard maps out of a series of 10 related to earthquakes, floods, landslides, mudflows, rockfall, snow avalanches, wildfire, windstorms, hailstorms and drought.
- Elements-at-risk maps: you can select one or more elements-at-risk maps out of a series of 7 related to: buildings, population, GPD, forest, protected areas, transportation infrastructure and pipelines.
- Administrative units: you can select to calculate the exposure per community, district or region of Georgia.

9.1   INTRODUCTION

One of the most important components of the risk assessment is the exposure analysis. The interaction of elements at risk and hazard defines the exposure. Earlier we have seen the 10 hazard types for which hazard maps have been prepared: Earthquake (EQ), Flooding (FL), Landslides (LS), Mudlfows (MF), Rockfalls (RF), Wildfires (WF), Snow Avalanches (SA), Drought (DR), Windstorm (WS) and Hailstorm (HS).

The following exposure types are made:
- **Buildings**: Number of buildings per hazard class & hazard type within the administrative unit
- **Population**: Number of people per hazard class & hazard type within the administrative unit
- **GDP**: Gross Domestic Product **in Lari** per hazard class & hazard type within the administrative unit
- **Road**: Length of roads (highways and paved roads) **in meters** per hazard class & hazard type within the administrative unit
- **Pipes**: Length of pipelines (oilpipelines and gaspipelines) **in meters** per hazard class & hazard type within the administrative unit
- **NatParks**: Area of Natural Parks (protected areas) **in hectares** per hazard class & hazard type within the administrative unit
- **Forests**: Area of Forests **in hectares** per hazard class & hazard type within the administrative unit
- **Crops**: Area of Crops **in hectares** per hazard class & hazard type within the administrative unit

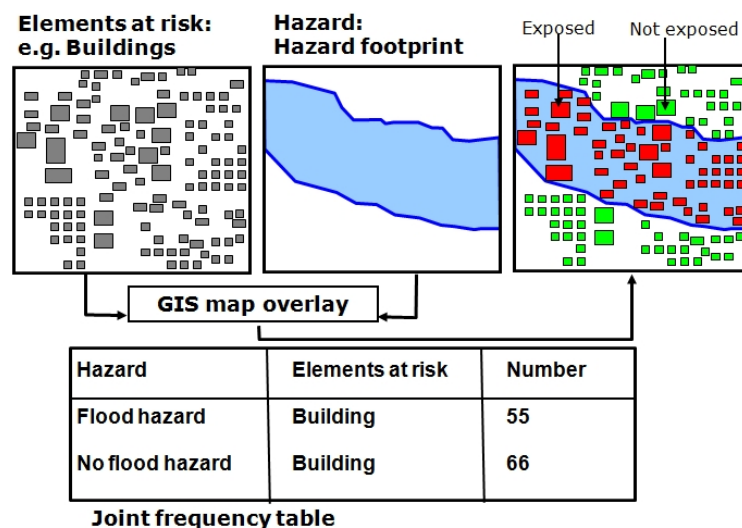The procedure for the generation of exposure maps is illustrated in the figure below.

Figure: Spatial overlay of hazard footprints and elements at risk provides information on exposure.

The calculation of the exposure was carried out using so-called script files (automated calculation files) using the ILWIS GIS software. The main steps in calculating the exposure are:

1. Overlay the hazard map with the elements at risk map, and create a joint frequency table, containing all existing combinations of the two maps, and also a map with all combinations.
2. Overlay this combination map with the administrative units (communities).
3. Calculate the number of elements at risk located in the three hazard classes (high, moderate and low)
4. Bring these values into an attribute table that is linked with the administrative unit map.
5. Calculate the percentage of elements at risk located in the three hazard classes (high, moderate and low)

- The results were stored in three large tables:
  o Exposure_communities: containing all exposure information per community
  o Exposure_districts: containing all information per districts
  o Exposure_regions: containing all information per regions
- The same exposure files were also used for the Web-GIS.

The calculation of the exposure was very time consuming, taking into account that there were 10 hazard maps and 8 types of elements at risk. In the following pages we will show you you to carry out the the above mentioned steps for a simple examples, and after that you can use a script to analyze the exposure of any hazard map, element-at-risk and administrative unit.

9.2   CALCULATION EXPOSURE WITH A SIMPLE EXAMPLE

In this section you will learn the procedure to calculate the exposure using a simple example. We will use the example of calculating the number of buildings exposed to earthquake hazard, for the different communities.

Step 1: Overlay the hazard map with the elements at risk map, and create a joint frequency table, containing all existing combinations of the two maps, and also a map with all combinations.

- Select Operations, Raster Operations, Cross
- Select first map: **EQHazard**
- Select second map: **Building**
- Select output table **EQBuilding**
- Click the option: Output map and type the name of the output map: **EQBuilding**
- Open the map **EQBuilding** and check the result

Step 2: Overlay this combination map with the administrative units (communities).

- Select Operations, Raster Operations, Cross
- Select first map: **EQBuilding**
- Select second map: **Community_ID**
- Select output table **CEQBuilding**

- Open the table **CEQBuilding** and check the result.

As you can see this is a very large table that contains all combinations of the Communities in Georgia, the earthquake hazard classes and the number of buildings. In order to use this we need to simplify these values. We first need to know for each combination what the hazard class is.

- Open the table **CEQBuilding** and select: *Columns, Join…*
- Select the table **EQBuilding**, and the column: **EQHazard** Click *Next*, *Next* and *Finsh*. The column EQ Hazard is now brought into the table CEQBuilding.
- Select again: *Columns, Join…*
- Select the table **EQBuilding**, and the column: **Buildings** Click *Next*, *Next* and *Finsh*. The column **Buildings** is now brought into the table **CEQBuilding**.

Step 3: Calculate the number of elements at risk located in the three hazard classes (high, moderate and low)

- In the Type on the command line of the table the following formula:
  Ex_high:=iff(EQHazard="high",building*Npix,0)
- Check the values in the statistics pane at the bottiom of the page. What is the total number of buildings in the high seismic hazard zone?
- Type on the command line of the table the following formula:
  Ex_mod:=iff(EQHazard="moderate",building*Npix,0)
- Type on the command line of the table the following formula:
 Ex_low:=iff((EQHazard="low")or(EQHazard="none")or(EQHazard="outside"),Building*Npix,0)

Step 4: Calculate the percentage of elements at risk located in the three hazard classes (high, moderate and low)

- Type on the command line of the table the following formula:
 EQ_Building_HighP := iff(Ex_High=0,0,100 * (Ex_High / (Ex_High + Ex_Mod + Exp_Low)))
 Check the values in the statistics pane at the bottiom of the page. What is the total number of buildings in the high seismic hazard zone?
- Type on the command line of the table the following formula:
 EQ_Building_ModP := iff(Ex_Mod=0,0,100 * (Ex_High / (Ex_High + Ex_Mod + Exp_Low)))
- Type on the command line of the table the following formula:
 EQ_Building_LowP := iff(Ex_Low=0,0,100 * (Ex_High / (Ex_High + Ex_Mod + Exp_Low)))

9.3   CALCULATION EXPOSURE USING A SCRIPT FILE

The exposure calculation is made in a script file. A script is a sequenced list of ILWIS commands and expressions. By creating a script, you can build a complete GIS or Remote Sensing analysis for your own research discipline. Lines in a script may contain commands for object management (e.g. copy or delete), display of data objects (open or Show), and for the creation and calculation of data objects. All MapCalc, and TabCalc formulas, and all ILWIS expressions to perform operations may be used. Other scripts and other Windows applications can also be called from within a script. A script can use parameters.
Parameters in a script replace (parts of) object names, operations, etc. Parameters in scripts must be written on the Script tab in the Script editor as %1, %2, %3, up to %9.

The script that we will use is called: **Exposure_script**. The content is indicated below.


```
// %1 , %2  and %3 are variables
// %1 is the hazard.
// You can select the following option: EQ (Earthquakes), FL (Flooding), LS (Landslides), MF (Mudflows), RF (Rockfall), SA (Snow Avalanche), WS (Windstorm),
// WF (Willdfire), DR (Drought), HS (Hailstorm)
// %2 is the type of elements-at-risl.
// You can select the following: Building (nr. Buildings per hectare), Population (nr. people per hectare), GDP (Gross Deomestic Produict per hectare), Crops , Forest
//%3 is the administartive unit:
//  - Communities
//  - District
//  - Region
//  - Country

Del %2%1*.* -force
Del C_%2%1%3*.* -force

del Exposure_%3.tb* -force
crtbl Exposure_%3.tbl %3.dom

//Step 1: Overlay the hazard map with the elements at risk map, and create a joint frequency table, containing all existing combinations of the two maps, and also a

%2%1.tbt := TableCross(%1hazard,%2,%2%1,IgnoreUndefs)

//Step 2: Overlay this combination map with the administrative units (communities).

C_%2%1%3.tbt := TableCross(%2%1,%3,IgnoreUndefs)

TabCalc C_%2%1%3  %1hazard := ColumnJoin(%2%1.tbt,%1hazard,%2%1)
TabCalc C_%2%1%3  %2 := ColumnJoin(%2%1.tbt,%2,%2%1)

TabCalc C_%2%1%3  Exposure_high:=iff(%1Hazard="high",%2*Npix,0)
TabCalc C_%2%1%3  Exposure_mod:=iff(%1Hazard="moderate",%2*Npix,0)
TabCalc C_%2%1%3  Exposure_low:=iff((%1Hazard="low")or(%1Hazard="none")or(%1Hazard="outside"),%2*Npix,0)

TabCalc Exposure_%3 %2_%1_High := ColumnJoinSum(C_%2%1%3.tbt,Exposure_high,%3,1)
TabCalc Exposure_%3 %2_%1_Mod := ColumnJoinSum(C_%2%1%3.tbt,Exposure_mod,%3,1)
TabCalc Exposure_%3 %2_%1_Low := ColumnJoinSum(C_%2%1%3.tbt,Exposure_low,%3,1)

// Calculate percentages
TabCalc Exposure_%3 %2_%1_HighP {dom=value;vr=::1} := iff(%2_%1_High=0,0,100 * (%2_%1_High / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
TabCalc Exposure_%3 %2_%1_ModP {dom=value;vr=::1} := iff(%2_%1_Mod=0,0,100 * (%2_%1_Mod / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
TabCalc Exposure_%3 %2_%1_LowP {dom=value;vr=::1} := iff(%2_%1_Low=0,0, 100 * (%2_%1_Low / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))


Del %2%1.tbt -force
Del C_%2%1%3.* -force
```

In this script we will be using 3 parameters: %1 , %2 and %3

- **%1 is the hazard**. You can select the following option: EQ (Earthquakes), FL (Flooding), LS (Landslides), MF (Mudlflows), RF (Rockfall), SA (Snow Avalanche), WS (Windstorm), WF (Willdfire), DR (Drought), HS (Hailstorm)
- **%2 is the type of elements-at-risk**. You can select the following: Building (nr. Buildings per hectare), Population (nr. people per hectare), GDP (Gross Deomestic Produict per hectare), Crops , Forest, NatParks (Natural Parks), Road , Pipes,
- **%3 is the administartive unit**: Communities, District, Region, Country

The content of the script closely follows the steps that you have carried out manually in the previous section of this exercise. We will run the script now for oone combination of the input parameters:

%1 = EQ (we will do this for the earthquake hazard map)

%2 = building (the elements a risk we will use for the exposure analysis are the buildings)

%3 = district (we will calculate the exposure for the districts)

- Type on the command line of the table the following formula:

Run Exposure_script EQ building district

With this statement we calculate the exposure of buildings to earthquake hazard and we represent the results per district.

- Open the resulting table: **Exposure_district** and check the result.

You can also visualize the results in a map: district. In order to do that we need to link the table Exposure_district first to the map District.

- Right click on the map **District** and select the option: *Attribute map*. Select the table **Exposure_district** and click *OK*.
- Now double-click the map **District**, and in the *Display Options* menu select *Attribute*, and select the column: **Building_EQ_High**.

Now the number of buildings that are exposed to a high earthquake hazard are shown per district.

- Which of the districts have a high exposure of buildings to earthquake? Read the values in the map.

You can also find the 5 districts with the highest number of exposed buildings directly from the attribute table.

- Open the table **Exposure_district**, and select *Columns, Sort*. Select the column **Building_EQ_high** and select *descending.*
- Copy the ten districts with the highest number of buildings exposed to high earthquake into an Excel table .

You can also find the 5 districts with the highest percentage of exposed buildings directly from the attribute table.

- Open the table **Exposure_district**, and select Columns, Sort. Select the column **Building_EQ_highP** and select descending.
- Copy the ten districts with the highest percentage of buildings exposed to high earthquake into an Excel table . Are these the same as the one with the highest absolute numbers?

9.4   CALCULATE THE EXPOSURE FOR DIFFERENT COMBINATIONS.

You can also make an analysis of many different combinations of exposure. For instance if you would like to make an analysis of all hazards for one element-at-risk, or the effect of one hazard on all elements-at-risk. Besides you can also decide to make an analysis at different administrative levels.
You can do that by making another script that will be used as input for the script: **Exposure_script**. Before doing that you need to adapt some lines in the script Exposure_script:

del Exposure_%3.tb* -force
crtbl Exposure_%3.tbl %3.dom
We want to remove these lines because they will delete each time the table with the results.

- Change these two lines, by adding two // in front. This will make that ILWIS will skip these two lines:
    //del Exposure_%3.tb* -force
    //crtbl Exposure_%3.tbl %3.dom
- Save the script **Exposure_script** again.
- Now create a new script. Select in the main window of ILWIS: File, Create, Script. Write the following line in the empty script.
    del Exposure_district.tb* -force
    crtbl Exposure_district.tbl district.dom
    (replace the word district with either: communities or region if you want to do the analysis on this level)
- After this you can add the lines for calculating the script for different parameters. For instance if we want to calculate the exposure for mass movement and flooding for crops per district you would write:
    Run exposure_script LS crops district
    Run exposure_script MF crops district
    Run exposure_script RF crops district
    Run exposure_script FL crops district
- Save the script now as **Input_exposure_script**
- Run this script **Input_exposure_script**

- The script will take some time, but when it is finished, you can then analyze the results in the table **Exposure_district**.

Now based on your interest you could do a more complicated exposure analysis. We have below some examples of the exposure analysis that can be done. Select one of the options and create your own input script file for that.

9.5   EXPOSURE OF FOREST AND CROPS.

One type of analysis could be to evaluate the exposure of forest and crops to high classes of wildfire, drought, and windstorm. We do this at the region level.

- Adapt the script **Exposure_script** and remove all the following lines (We are only interested in the high exposure classes):

```
TabCalc Exposure_%3  %2_%1_Mod := ColumnJoinSum(C_%2%1%3.tbt,Exposure_mod,%3,1)
TabCalc Exposure_%3  %2_%1_Low := ColumnJoinSum(C_%2%1%3.tbt,Exposure_low,%3,1)
// Calculate percentages
TabCalc Exposure_%3 %2_%1_HighP {dom=value;vr=::1} := iff(%2_%1_High=0,0,100 * (%2_%1_High / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
TabCalc Exposure_%3 %2_%1_ModP {dom=value;vr=::1} := iff(%2_%1_Mod=0,0,100 * (%2_%1_Mod / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
TabCalc Exposure_%3 %2_%1_LowP {dom=value;vr=::1} := iff(%2_%1_Low=0,0, 100 * (%2_%1_Low / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
```

- Create the input script for all combinations:

```
del Exposure_region.tb* -force
crtbl Exposure_region.tbl district.dom
run Exposure_script WF forest region
Run Exposure_script DR forest region
Run Exposure_script WS forest region
etc.. etc..
```

- Save the script as **Input_Exposure_script**
- The script will take some time, but when it is finished, you can then analyze the results in the table **Exposure_district**.
- Check your results with those reported in the atlas of Georgia.

Which region has the highest exposure of forests? Due to which hazard?
Which region has the highest exposure of crops? Due to which hazard?
How much of the forest area is exposed to high wildfire hazard, and to high windstorm hazards?

9.6   EXPOSURE OF BUILDINGS

Another type of analysis could be to evaluate the exposure of buildings to high classes of Earthquake, Flooding, Landslide, and Wildfire. We do this also at the region level.

- Adapt the script **Exposure_script** and remove all the following lines (We are only interested in the high exposure classes):

```
TabCalc Exposure_%3  %2_%1_Mod := ColumnJoinSum(C_%2%1%3.tbt,Exposure_mod,%3,1)
TabCalc Exposure_%3  %2_%1_Low := ColumnJoinSum(C_%2%1%3.tbt,Exposure_low,%3,1)
// Calculate percentages
TabCalc Exposure_%3 %2_%1_HighP {dom=value;vr=::1} := iff(%2_%1_High=0,0,100 * (%2_%1_High / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
```

```
TabCalc Exposure_%3 %2_%1_ModP {dom=value;vr=::1} := iff(%2_%1_Mod=0,0,100 * (%2_%1_Mod / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
TabCalc Exposure_%3 %2_%1_LowP {dom=value;vr=::1} := iff(%2_%1_Low=0,0, 100 * (%2_%1_Low / (%2_%1_High + %2_%1_Mod + %2_%1_Low )))
```

- Create the input script for all combinations:

```
del Exposure_region.tb* -force
crtbl Exposure_region.tbl district.dom
run Exposure_script EQ building region
Run Exposure_script FL building region
Run Exposure_script LS building region
Run Exposure_script WF building region
```

- Save the script as **Input_Exposure_script**
- The script will take some time, but when it is finished, you can then analyze the results in the table **Exposure_district**.
- Check your results with those reported in the atlas of Georgia.
- Fill in the table below.

The table below list the 10 communities in Georgia with the highest exposure of buildings for earthquakes, flooding, landslides and wildfires.

	Earthquake	Flood	Landslides	Wildfire
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

10 CALCULATING RISK FOR MULTI-HAZARDS AND DIFFERENT ELEMENTS-AT-RISK.

Expected time: 3 hours

Data: **Exercise_Risk.zip**

Objectives: After this exercise you will be able to generate:

- Risk maps expressing the expected losses within a time period of 50 years.
- The analysis is done for the exposure maps generated from the hazard maps for 10 hazards related to earthquakes, floods, landslides, mudflows, rockfall, snow avalanches, wildfire, windstorms, hailstorms and drought, and for elements-at-risk maps (buildings, population, GPD, forest, protected areas, transportation infrastructure and pipelines).
- The exercise is dealing first with the analysis of the spatial probability of occurrence of an event within a pixel of 100 by 100 meters within a 50 years period. This is partly derived from historical information, but as the data is not sufficient also expert opinion will be important in this stage.
- The second component is the estimation of the physical vulnerability, as the degree of loss to the element at risk if a hazard would occur. This is mainly expert based.

10.1   INTRODUCTION

The risk assessment method is a semi-quantitative method that estimates the level of expected losses for a certain reference period, using the following equation:

Risk = H * V * A

> H = Hazard, expressed as the chance that a basic unit of 1 hectare in one of the hazard classes is actually hit by a hazard event in a reference period of 50 years. This is referred to as the spatial probability of occurrence;
> V = Physical vulnerability of the particular element-at-risk, expressing the probability of complete loss of the elements at risk of the same class given the occurrence of the hazard event.
> A = Amount of exposed elements-at-risk, calculated by overlaying in a GIS the hazard classes with the elements at risk and calculating the number of elements at risk per hazard class in each community.

First we have calculated the amount of exposure of different elements-at-risk (buildings, population, GDP, forest, crops and protected areas) for each of the 10 hazard types (earthquakes, floods, landslides, mudflows, rockfall, snow avalanches, wildfires, drought, hailstorms and windstorms). The exposure is calculated for the three classes of each of the hazard maps (High, moderate and low). This was done in the previous exercise and in this exercise we will use the results for all hazards, and all elements at risk, based on the lowest administrative level: communities.

The hazard is expressed as the **spatial probability** that a certain area is expected to be impacted by one of the hazard types within a given reference period. In this study we used a reference period of 50 years. In order to estimate the spatial probability of occurrence, we analyzed the historical catalogues of the various hazard types, and extracted the number of events that are likely to occur in a period of 50 years. Next we estimated the area affected by one event (e.g. for landslide an area of 5000 m^2) and multiplied this with the number of expected events. The resulting value expresses the estimated area that might be impacted by a specific hazard in a reference period of 50 years. This was then divided by the total area of the hazard class in order to obtain the spatial probability of occurrence.

The **vulnerability** is evaluated as the degree of damage that is likely to occur to a particular element-at-risk given the impact of a certain type of hazard. Given the national scale and the fact that we cannot differentiate the degree of intensity we have adopted single vulnerability values for each of the elements-at-risk and hazard types. The table on the next page indicates the various values used.

The resulting risk values can be compared for the various hazard types, and could also be compared among a number of elements-at-risk (e.g. number of buildings, area of forest, crops or protected areas when converted to monetary values).

The values are only approximations and contain a high degree of uncertainty as the analysis is based on a number of assumptions, related to the estimation of the hazard zones, the

estimation of the impacted area, spatial probability, vulnerability and exposure. Even though the results are highly uncertain, they do allow the comparison of the impact of the various types of hazards, and the order of magnitude of expected impacts. When more detailed information becomes available, this method can be further improved.

10.2   ESTIMATION OF SPATIAL PROBABILITY

For the estimation of the spatial probability and the vulnerability we followed an extensive reasoning which you could best follow by using an Excel table that gives the information.

- Open the Excel table: **Risk_estimation_input**.

The table gives a number of input fields. After the "*Hazard Co*de" the next field is the "*Hazard class*". As you can see we have assumed that, except for the earthquake affected areas, the other hazards will have very low impacts in the low hazard class, and therefore we didn't include these in the table. The next field is "*Area of Hazard Class in m2*" This information is obtained from the histograms of the various hazard maps. For example:

- In ILWIS, right click on the map **EQHazard** and select Statistics, Histogram.
- Open the histogram and compare the areas of the high, moderate and low classes with the ones in the Excel table.

The next field in the table is the "*Area of Hazard Class in km2*" This information is obtained directly obtained by dividing the "*Area of Hazard Class in m2*" by 1 million.
The third field in the table is the "*Historic events in the database*" This information is obtained from the various historical databases that were available for the various hazards.

- The historical events can be found using the web-GIS application. They are also stored in an attribute table **Community_ID**. Open the table **Community_ID** and read the values from the statistics pane at the bottom of the page, wich indicates the total number of events. Compare these with the values in the Excel sheet.

For the estimation of the spatial probabilities the following assumptions were made:

10.2.1 Spatial probability of earthquakes

- For **earthquake risk** we examined the information on historical earthquakes in the country, and based on this we assumed that :
  - o One earthquake with Magnitude around 7 is likely to occur in Georgia in the coming 50 year.
  - o the impact area was around 50 by 50 km,
- Given the estimated size of the affected area
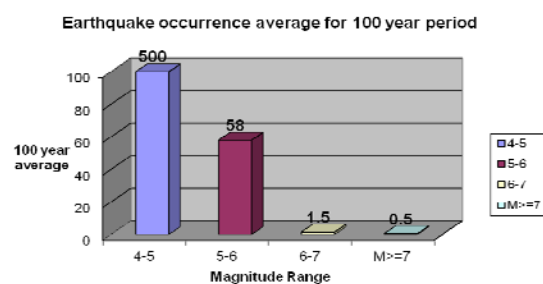
as a fraction of the total area of the hazard class, we estimated a spatial probability:
  - of 0.08 for areas located in the high hazard zone to be affected by an earthquake in the coming 50 years,
  - 0.01 for areas located in the moderate zone, and
  - 0.007 for areas located in the low hazard zones.

10.2.2 Spatial probability of floods

For **flood risk** assessment, we cannot base ourselves on the historic information from the disaster database, as the same flood would affected several communities. Therefore we assumed that:
- 30 flood events were likely to occur within the various rivers in the country in a period of 50 years in the high and moderate zone

These events include both flashfloods (which have generally smaller areas affected), and river floods (with larger affected areas). Given fact that the flood model narrowed the areas susceptible to flood as much as possible, the spatial probability of flooding is estimated to be:
- 0.9 in the the high hazard zone
- 0.4 in the moderate zone 0.4, and
- 0 in the low hazard zone for the 50 year period.

10.2.3 Spatial probability of mass movements

For the **risk to mass movements,** which was separated in landslides, mudflows and rockfalls, we used the number of events that have occurred in the entire historic database as an estimation of the number likely to occur in the coming 50 years. This was done because the number of events in the database is probably a large underestimation of the actual number of events that have happened (due to incompleteness of the historical inventory). We assumed also that 90 percent of the events occurred in the high hazard zones, and 10 percent in the moderate zone, and very few events in the low hazard zones. That is why we do not include the low hazard zones in the risk calculation.

The average area of an individual mass movement event was estimated to be 5000 m^2 for landslides, 4500 m^2 for mudflows, and 800 m^2 for rockfall events. We multiplied the number of expected events with the average size, and divided this by the total area of the hazard classes. This resulted in the values for the spatial probability, which were generally quite small (e.g. 0.0002 for the high hazard class of landslides), given the large size of the high and moderate hazard areas, and the limited number of events.

- Check the number of events in the attribute table **Community_ID**. Check the calculation method for the spatial probability of landslides, mudlfows and rockfall in the Excel sheet (**Risk_analysis_input**).

If a better modeling approach could be used for the landslide hazard assessment, this would reduce the surface areas of the high and moderate classes considerably and give higher spatial probability values.

10.2.4 Spatial probability of snow avalanches

A similar approach was followed for the estimation of the spatial probability of **snow avalanches.** The number of events in the historical database was used to estimate the future frequency in a 50 year period (687), with 90 percent occurring in the high hazard class. Given the relatively small average area of snow avalanches (2 hectares, a stretch of 50 y 400 meters) the spatial probability of

occurrence was also low (0.0018 in the high hazard class). This could be much larger if the high hazard zones would cover less area, as is the case now.

Table :. Data used for the estimation of spatial probabilities for the 10 hazard types.

Hazard	Class	Area (km^2)	Nr events	Single event area (km^2)	Total event area (km^2)	Spatial probability
Earthquake	High	31487.99	1 (M ≥ 7)	2500	2500	0.08
	Mod	23746.29	1 (M ≥ 7)	400	400	0.01
	Low	14421.72	1 (M ≥ 7)	100	100	0.007
Floods	High	6174.89	30	185	5557	0.9
	Mod	505.22	30	7	202	0.4
	Low	180.17	5	5	25	0.139
Landslides	High	15564.98	680	0.005	3.4	0.000218
	Mod	28246.55	76	0.005	0.38	0.0000134
	Low	25844.47	5	0.005	0.05	0.00000097
Mudflows	High	8621.23	383	0.025	9.585	0.00111
	Mod	39294.15	41	0.025	0.3195	0.0000271
	Low	21740.62	5	0.025	0.125	0.00000575
Rockfall	High	8046.97	92	0.0008	0.073	0.0000091
	Mod	34987.54	10	0.0008	0.00816	0.0000002
	Low	26621.49	0	0.0008	0	0
Snow Avalanches	High	6853.09	601	0.02	12.024	0.00175
	Mod	15434.67	67	0.02	1.336	0.0000866
	Low	47368.24	0	0.02	0	0.0000000
Wildfires	High	12521.9	482	0.1	48.2	0.00385
	Mod	30332.18	54	0.1	5.4	0.000177
	Low	26801.92	5	0.1	0.5	0.0000187
Drought	High	4375.12	10	350	3500	0.8
	Mod	12151.15	5	350	1750	0.144
	Low	53129.73	1	350	700	0.0132
Windstorm	High	8764.04	303	17	5258	0.6
	Mod	45163.16	34	17	5843	0.013
	Low	15728.8	5	17	85	0.0054
Hailstorm	High	6468.29	275	2	550	0.085
	Mod	33931.88	69	2	138	0.004
	Low	29255.83	5	2	10	0.00034

10.2.5 Spatial probability of wildfires, drought, hailstorms and windstorms

For the estimation of the **spatial probability of wildfires** we used the number of reported wildfire events in the historic database (533) as an indication of the number of future events in a period of 50 years, and used 3 hectares as the average area affected by one event. The resulting spatial probability values were rather small: 0.039 (high hazard) and 0.0018 (moderate hazard).
For the estimation of the spatial probability of **drought risk** we used a frequency of 10 droughts in a period of 50 years in the high hazard, affected 80 % of the high hazard territory, and 5 droughts in the moderate hazard class affecting 14 %.
Finally, for the estimation of the spatial probability of hailstorms and windstorms, we used the total number of recorded events (328 for windstorms and 342 for hailstorms) as indicative values for the

frequency in the coming 50 years. The average size of windstorm events was estimated to be much larger (17 km^2) than for hailstorms (2 km^2) in which we also included lightning effects. The resulting spatial probability for windstorms were 0.5 (for the high hazard zones) and 0.02 (for the moderate hazard zones), and for hailstorms/lightning these values were 0.085 (high hazard zone) and 0.004 (moderate hazard zone).

- Check the number of events in the attribute table **Community_ID**. Check the calculation method for the spatial probability in the Excel sheet (**Risk_analysis_input**). What would be needed as additional data in order to improve these results?

10.3   ESTIMATION OF VULNERABILITY

Apart from the spatial probability also the physical vulnerability needs to be estimated, as these two factors are needed in the calculation of the risk. For the estimation of physical vulnerability we have very little hard evidence, and need to rely even more on expert reasoning.

For **earthquakes**, we assumed that:
- o   Intensities up to 9 (MSK scale) are expected to occur in the high seismic hazard zone,
- o   Intensities up to 7 (MSK scale) are expected to occur in the moderate zone
- o   Intensities up to 6 (MSK scale) are expected to occur in the low seismic hazard zone.

For the estimation of the physical vulnerability of buildings, we evaluated the average vulnerability of different types of buildings given the intensities listed above. Although for some parts of the area information was also available on vulnerability types, we decided to use the average values which could be used for the entire county. This resulted in the use of a vulnerability value of:
- 0.3 for the high hazard class,
- 0.1 for the moderate hazard class and
- 0.02 for the low hazard zone.

For the estimation of population losses we used vulnerability values of
- 0.005 (high hazard),
- 0.001 (moderate) and
- 0.0005 (low).

Vulnerability values for forests, crops and protected areas were considered to be very low and taken as 0. Of course these values are simplifications of the actual situation, and the resulting loss estimation is only a relative value. More detailed analysis of earthquake hazard and risk is required incorporating the actual range of expected PGA values and not the classification in 3 (arbitray classes), and taking into account the different building types per hectare, and using different vulnerability classes.

With respect to the physical vulnerability used for **floods** we used an average vulnerability of:
- 0.2 for the high hazard zones (assuming that in most cases the structural damage to buildings is low but the damage to contents may be high),
- 0.05 for the moderate hazard zone, and
- 0.01 for the low hazard zone.

A large part of the country falls in the category "no hazard" and these areas therefore also have no flood risk. Population vulnerability values for flooding were considered very low, as in most cases people have ample time to evacuate from the flood affected areas, or can escape to higher floors in flood resistant buildings. We used the following values: 0.001 (high hazard), 0.0001 (moderate hazard) and 0.00005 (low hazard). Flood vulnerability for forests and protected areas was considered relatively low, but for crops fairly high vulnerability values were used: 0.7 (high hazard zones), 0.5 (for moderate hazard zones) and 0.1 (for low hazard zones).

Landslide vulnerability
The physical vulnerability values for buildings and population were considered to be relatively high for landslides, mudflows, and rockfall, considering the fact that if a building or a person would be hit by a mass movement, the impact would be high.

Snow avalanche vulnerability
We used higher physical vulnerability values for population as we did for mass movements, as we considered that people that are expected to be hit by snow avalanches, are either on the road or skiing. We therefore increased the number of exposed residents exposed to snow avalanches by a factor of 4 to account for winter tourism.

Wildfire vulnerability
The physical vulnerability of population was estimated as very low (0.002) considering the warning time which generally allows people to flee from wildfires. The physical vulnerability for wildfire was estimated to be very high for forests, crops and natural parks.
For drought vulnerability For the physical vulnerability we used only values for forest, natural parks and particularly crops. For the latter the following vulnerability values were used: 0.6 (for high hazard), 0.3 (for moderate hazard zones) and 0.01 (for low hazard zones).

Wind storms and hailstorm vulnerability
For the physical vulnerability of people, we used the following values: 0.0005 (for high hazard zones) and 0.0001 (for moderate hazard zones). Vulnerability values for crops were much higher for hailstorms (0.8 for high hazard zones, and 0.2 for moderate zones) than for windstorms (0.01 for high and 0.005 for moderate zones). For windstorms forests and natural parks had high vulnerability values (0.1 and 0.05).

- Check these vulnerability values in the Excel sheet (**Risk_analysis_input**). What would be needed as additional data in order to improve these results?

Table: Data used for the estimation of physical vulnerability for the main types of elements-at-risk and for the 10 hazard types.

Hazards		Estimated physical vulnerability values						
Hazard type	Class	Buildings	Population	GDP	Transport	Forests	Crops	Protected area
Earthquake	High	0.3	0.005	0.7	0.01	0	0	0
	Mod	0.1	0.001	0.3	0.005	0	0	0
	Low	0.02	0.0005	0.1	0.001	0	0	0
Floods	High	0.1	0.0005	0.7	0.1	0.005	0.7	0.005
	Mod	0.05	0.0001	0.3	0.05	0.001	0.5	0.001
	Low	0.01	0.00001	0.1	0.01	0.0005	0.1	0.0005
Landslides	High	1	0.5	0.7	1	0.05	0.7	0.05
	Mod	0.5	0.2	0.3	0.5	0.01	0.5	0.01
	Low	0.01	0.01	0.1	0.01	0.005	0.1	0.005
Mudflows	High	1	0.5	0.7	1	0.05	0.7	0.05
	Mod	0.5	0.2	0.3	0.5	0.01	0.5	0.01
	Low	0.01	0.01	0.1	0.1	0.005	0.1	0.005
Rockfall	High	1	0.5	0.7	1	0.05	0.01	0.05
	Mod	0.5	0.2	0.3	0.5	0.01	0.005	0.01
	Low	0.01	0.01	0.1	0.1	0.005	0.001	0.005
Snow Avalanches	High	1	0.8	0.7	1	0.1	0	0.1
	Mod	0.5	0.3	0.3	0.5	0.05	0	0.05
	Low	0.01	0.01	0.1	0.1	0.005	0	0.005
Wildfires	High	0.05	0.002	0.7	0.05	0.9	0.9	0.9
	Mod	0.01	0.0005	0.3	0.01	0.7	0.7	0.7
	Low	0.001	0.0001	0.1	0.005	0.1	0.1	0.1
Drought	High	0	0	0.2	0	0.001	0.6	0.001
	Mod	0	0	0.1	0	0.0005	0.3	0.0005
	Low	0	0	0.05	0	0.0001	0.01	0.0001
Windstorm	High	0.05	0.001	0.7	0.01	0.01	0.01	0.01
	Mod	0.01	0.0001	0.3	0.005	0.005	0.005	0.005
	Low	0.001	0.00001	0.1	0.001	0.001	0.001	0.001
Hailstorm	High	0.005	0.0005	0.7	0	0.01	0.8	0.01
	Mod	0.001	0.0001	0.3	0	0.005	0.2	0.005
	Low	0.0001	0.00001	0.1	0	0.001	0.01	0.001

10.4   GENERATING A SCRIPT FOR RISK ASSESSMENT

The actual risk calculation is done using a number of script files. For example, for buildings we have a script file called Building_risk.

// First the spatial probability
//Then the physical vulnerability
Tabcalc Exp_com_building EQloss {dom=value;vr=::0.001}:=
(EQ_high*0.08*0.3)+(EQ_mod*0.01*0.1)+(EQ_low*0.007*0.02)
Tabcalc Exp_com_building FLloss {dom=value;vr=::0.001} := (FL_high*0.8*0.1)+(FL_mod*0.4*0.05)
Tabcalc Exp_com_building LSloss {dom=value;vr=::0.001} := (LS_high*0.000218*1*5)+(LS_mod*0.0000134*0.5)
Tabcalc Exp_com_building MFloss {dom=value;vr=::0.001} :=(MF_high*0.00111*1*5)+(MF_mod*0.0000271*0.5)
Tabcalc Exp_com_building RFloss {dom=value;vr=::0.001} := (RF_high*0.0000091*1*50)+(RF_mod*0.0000002*0.5)
Tabcalc Exp_com_building SAloss {dom=value;vr=::0.001} :=(SA_high*0.00175*1*10)+(SA_mod*0.0000866*0.5)
Tabcalc Exp_com_building WFloss {dom=value;vr=::0.001} :=(WF_high*0.00385*0.05)+(WF_mod*0.000177*0.01)
Tabcalc Exp_com_building DRloss {dom=value;vr=::0.001} :=(DR_high*0.8*0)+(DR_mod*0.144*0)
Tabcalc Exp_com_building WSloss {dom=value;vr=::0.001} :=(WS_high*0.5*0.05)+(WS_mod*0.013*0.01)
Tabcalc Exp_com_building HSloss {dom=value;vr=::0.001} :=(HS_high*0.085*0.005)+(HS_mod*0.004*0.001)
Tabcalc Exp_com_building Total {dom=value;vr=::0.001} :=
EQLoss+FLloss+LSloss+MFloss+RFloss+WFloss+SAloss+DRloss+WSloss+HSloss

As you can see each line of this script calculates the risk for one type of hazard.And in each line the risk is calculated by multiplying:
Risk = Exposed elements * spatial probability * vulnerability

The values for the spatial probability and vulnerability are the ones that we have just analyzed. The exposed elements at risk were calculated in the previous exercise.

- Run the script: **Building_Risk** and check the results in the Table **Exp_Com**?
- You can also run the scripts for the other types of risk:
    - **Population_risk**
    - **Crops_risk**
    - **Forest_risk**
    - **GDP_risk**
    - **NatParks_risk**
    - **Transport_risk**
- Select one of these types of losses, and run the script, and analyze the results.
- You can also make maps of the resulting risk, by displaying the losses as an attribute map. Practice this for some of the types of risk
- Make also a selection based on the result, which of the hazards is most important for the type of elements at risk. Make a list of most important hazards.

10.5 ANALYZING THE RESULTS

The results of the risk estimation for the 10 different hazard types are stored in n table . This table shows the estimated losses in number of buildings, without subdividing the buildings into different types and vulnerability classes. This is a general estimation and future work should make this more detailed by including specific vulnerability curves for buildings of different types and using different intensities. The risk to population is expressed as the number of people likely to be killed by natural hazards in the reference period of 50 years. We have evaluated these values against the number of casualties that occurred in the past and they are in agreement. The risk in terms of GDP is expressed as the GDP losses in million Gel in the reference period. Note that this is not the same as the economic losses, as the actual value of the elements at risk (buildings, roads, infrastructure) has not been included in this figure.

The risk to roads is expressed as the length of roads likely to be destroyed (in km), and the risk to forest, crops and natural parks is expressed as the number of hectares likely to be lost. When evaluating the results, earthquakes and flooding constitute the largest risk in Georgia, in terms of buildings, number of people and in terms of GDP. Droughts, floods and wildfire form the largest risk to forest, crops and natural parks in Georgia.

You can also aggregate the risk by regions, using aggregation function of ILWIS.
- Open the table Region, and select Column, Join, and join with the table of risk that you calculated in the first part (e.g. Exp_com_building). You can then aggregate the loss values for the regions of Georgia.
- Aggregate the risk by regions and ranks the regions in terms of the risk that you selected. Find out the five regions with the higest risk.

Note: the values are only indicative as the estimation was based on a number of assumptions, of which the main ones are
- the hazard maps are general ones and consist only of 3 classes, and are made using simplified methods given the availability of data at a national scale;
- the spatial probability estimation (as shown in Table 1) depends to a large degree on the detail of the hazard estimation (the smaller the high hazard units are the better the prediction will be) and on the data of historical occurrences from the incomplete historical database;
- the vulnerability (See table 2) is a general approximation, and doesn't take into account the different degrees of intensity and the different classes of elements at risk (e.g. building types).

Table : Estimated risk for the 9 regions of Georgia.

Region	Population	Buildings	GDP Million Gel	Roads (km)	Forest (hect.)	Crops (hec.)	Natural Parks (hect.)
Kakheti	119	2651	71.571	10.916	258.337	30532.093	417.39
Samegrelo_Zemo_Svaneti	76	2506	117.799	27.602	567.896	6607.194	49.291
Kvemo Kartli	38	1249	243.353	15.074	140.939	28577.413	10.985
Imereti	41	1031	63.3	27.945	74.317	3262.151	10.482
Tbilisi	36	272	816.948	7.284	7.826	1259.637	0.049
Apkhazeti	191	1753	0.014	23.025	443.356	155.53	168.076
Shida_Kartli	25	1006	42.952	21.992	170.205	6486.866	6.543
Samtskhe_Javakheti	33	961	38.287	16.501	65.326	5127.606	64.518
A.R. of Achara	48	482	41.043	11.203	36.102	868.535	6.067
Mtskheta_Mtianeti	21	490	36.215	7.857	261.161	459.248	54.708
Racha_Lechkhumi_Kvemo_Svaneti	34	1177	52.762	10.889	663.362	91.58	0
Guria	7	218	14.387	6.478	40.992	4384.401	33.564
total	**669**	**13795**	**1538.63**	**186.766**	**2729.82**	**87812.25**	**821.67**

- Discuss these results. How reliable are they? How could you validate these? Would these data be constant for the next 50 years? If not, what should be changed?

11 CARTOGRAPHIC HAZARD & RISK MAPPING

11.1   HILLSHADE USING ILWIS AND ARCGIS

With the use of ILWIS and SRTM data hill shading as backdrop image for the base map will be created.

Expected time: 1 hr
Data: SRTM data from blackboard
Script: Colored Hillshade from DEM (Blackboard)
Objectives: After this exercise you will be able to generate:
   An hillshading in ILWIS by using SRTM data fit for use as a backdrop image for an Atlas Basemap.

Download SRTM files

First step in the process is the download of the SRTM files that cover the complete map area. For this it is of course important to know the full extent of the map-area. In the case of this example it covers Georgia and some area around. The coordinates for a complete coverage of the area are:
TopLeft 44N 439E / TopRight 44N 47E
BottemLeft 40N 39E / BottemRight 41N 47E
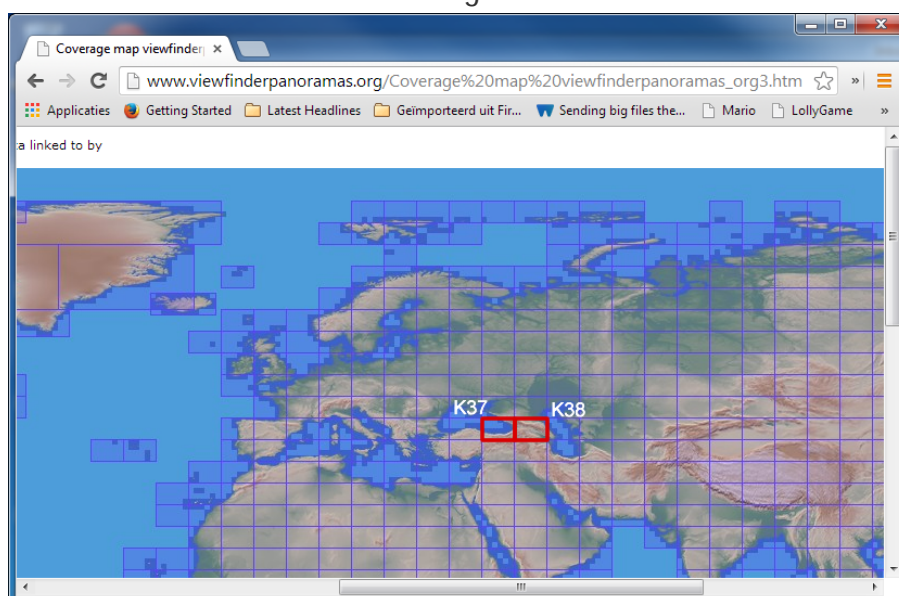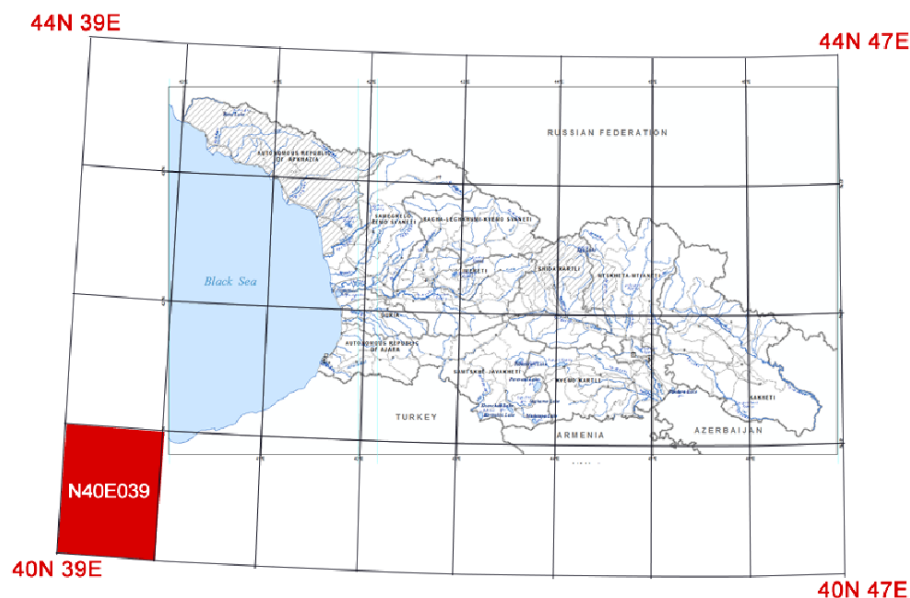
SRTM tiles are arranged per Degree, and accordingly numbered, where the tiles origin is the Lower left corner. The red indicated SRTM tile has tile number N40E039.

Download location

http://www.viewfinderpanoramas.org/Coverage%20map%20viewfinderpanora mas_org3.htm

Download the files in a separate folder.

Import raster *.hgt files in ILWIS

Start ILWIS 3.8.4 and identify the folder in which the downloaded raster files are loaded.
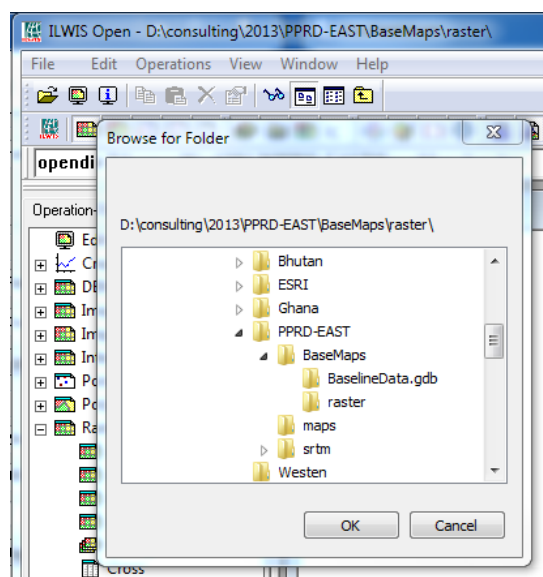
The folder does NOT show any content, raster files needs to be "imported" to be further recognized by ILWIS.
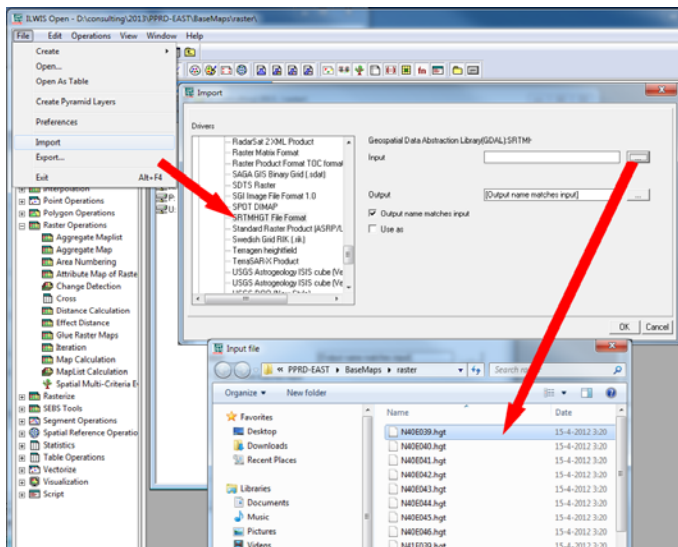
- Select from the Import Window the:
- [Geospatial Data Abstraction Library (GDAL)/Raster/SRTMHGT File Format]

After selecting the raster file and accept by clicking [OK] the file is imported as a folder in ILWIS.
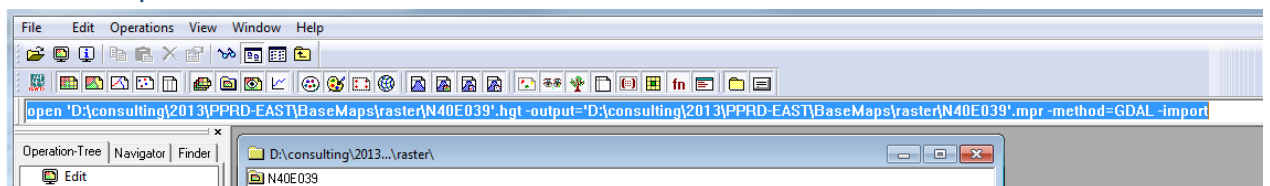
Activate the tab [Operation-Tree] and select from [Raster Operations/Glue Raster Maps].

In the "Command Line" at the top (highlighted in blue" the code for this "import action" is displayed. The other raster files will be imported by editing this command-line, which will be faster than repeating the previous actions.

```
Edit the command-line:
open 'D:\consulting\2013\PPRD-
EAST\BaseMaps\raster\N40E039'.hgt -
output='D:\consulting\2013\PPRD-
EAST\BaseMaps\raster\N40E039'.mpr -method=GDAL -import
The two highlighted file names need to be changed in
file names that stil need to be imported:
open 'D:\consulting\2013\PPRD-
EAST\BaseMaps\raster\N40E040'.hgt -
output='D:\consulting\2013\PPRD-
EAST\BaseMaps\raster\N40E040'.mpr -method=GDAL -import
```


After change press the [↵] (Return Key) on the Keyboard.
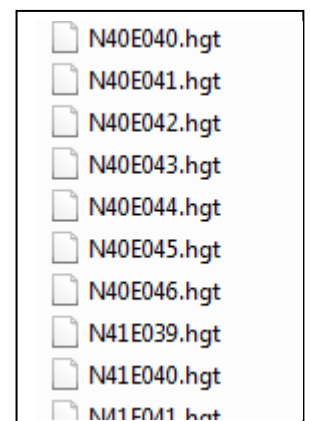
Repeat this for all files that have to be imported.

For further processing it is easier to release the files from their folders:

Right-Mouse click on a folder and select the option [Delete] from the
contextual menu.
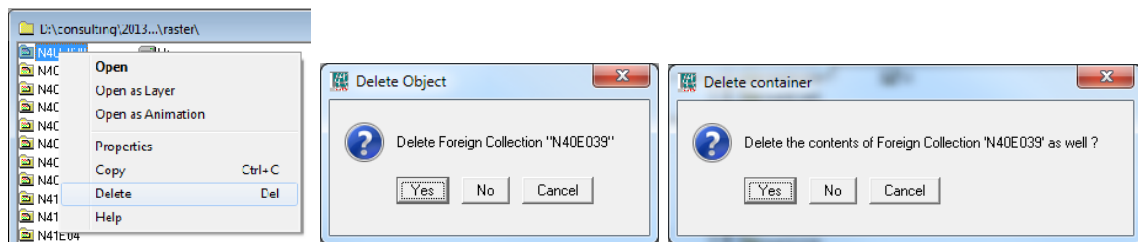
For the question "Delete Foreign Collection…?" select [Yes].
For the question "Delete the contents of Foreign Collection…?" select [No]
Repeat this for all other folders that contain the imported raster files.

The folder will contain now a collection of "Raster-" (N40E040),
"Coordinate-" (N40E040) and "Georeference-" (N40E040) files.
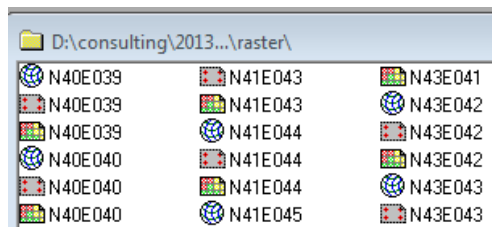
Glue tiles to one DEM with ILWIS

Preparations for creating one DEM for Georgia are finished. All separate files
need to be "Glued" to one complete DEM.

In ILWIS activate the [Operation-Tree] tab and select by double-clicking
[Raster Operations/Glue Raster Map].

The menu that appears allows only a maximum of four Input Maps, our
collection has 30 files. Again the Command-line will be used to perform the
operation.
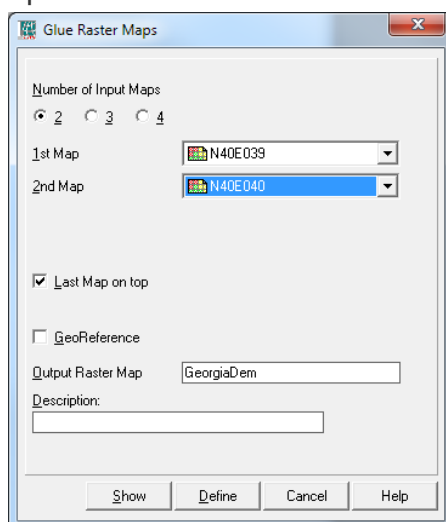
Use the Window "Glue Raster Maps" to make the first selection, give the Output Raster Map an appropriate name (eg. GeorgiaDem). Avoid if possible special characters like " */ , .-" etc. They may cause problems in further processing.

Press [Define]

A new raster file is added to your project folder, but more important is the code in the command line, which we will complete for all files required for the Glue operation. The code for the "Glue" operation for two files:

```
GeorgiaDem.mpr = MapGlue(N40E039,N40E040,replace)
```

Complete the code by adding all files:

```
GeorgiaDem.mpr = MapGlue(N40E039,N40E040,N40E041,N40E042,
   N40E043,N40E044,N40E045,N40E046,N41E039,N41E040,N41E041,N4
   1E042,N41E043,N41E044,N41E045,N41E046,N42E040,N42E041,N42E
   042,N42E043,N42E044,N42E045,N42E046,N43E039,N43E040,N43E04
   1,N43E042,N43E043,N43E044,N43E045,N43E046,replace)
```

After change press the [↵] (Return Key) on the Keyboard. You will get the warning that the "GeorgiaDem" file already exists, replace this by the new one.

To start the actual operation, double-click the "GeorgiaDem" raster file in your directory.

This process will take some considerable time. The result that is shown after processing is not the final, close this window and re-open it by double clicking on the GeorgiaDem raster file. The complete result is shown.
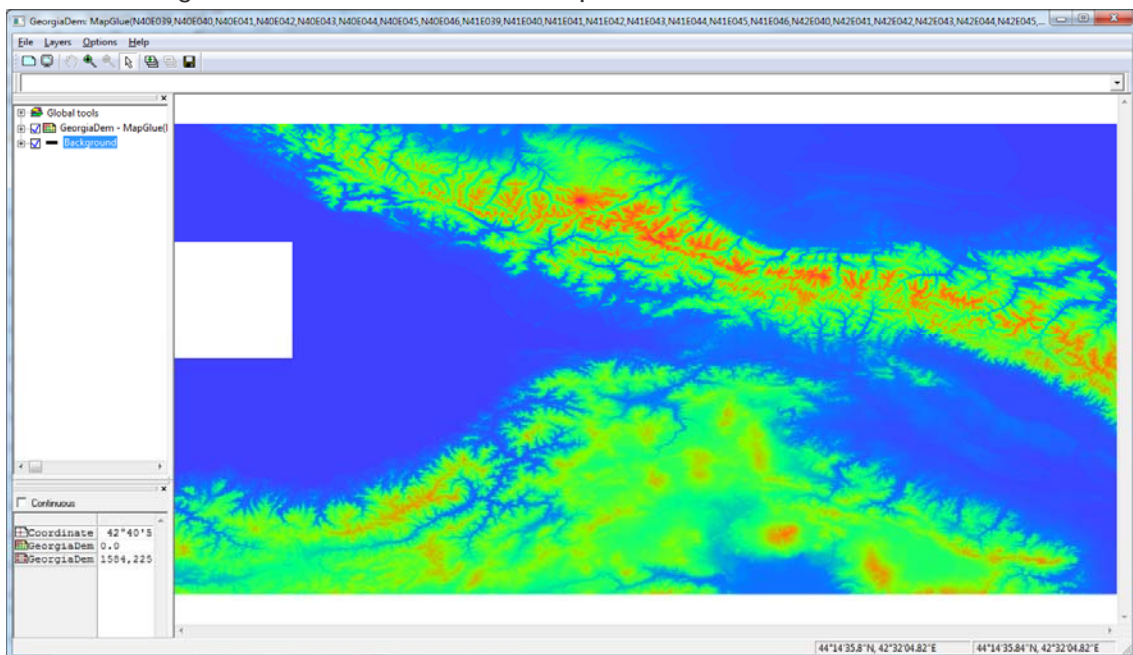
Make hill shading

To have a correct geo-referenced final hillshading, the dependency of the complete Dem of Georgia has to be "broken" with all separate rasterfiles used for the Dem. The reason is that ArcGis will not be able to interpret the position and orientation of the final output properly, resulting in a displaced hillshading.

> Right mouse click on the Georeference file of GeorgiaDem , from the contextual menu select the option [Properties]. Select the "Dependency" tab and select the [Break Dependency Link] button. In the pop up window "Break Dependency Link" select [Yes].

For creation of the hill shading a ready-made script will be used:
Colored Hillshade from DEM.
This script makes use of standard operations in ILWIS, such as MapFilter, MapStretchLinear, conversion to TIFF and JPEG and creation of a color composite. This script will NOT delete some intermediate files as the operation [DEN hydro-processing/DEM visualization] does. The separate Red Green and Blue intermediates will be used to create the hill shading in ArcGis. The script can be studied by opening it in a text editing software like Notepad.

> Open the script in ILWIS by double click. Run the script by clicking the [Run Script] ▶ button or by selecting [File/Run Script].
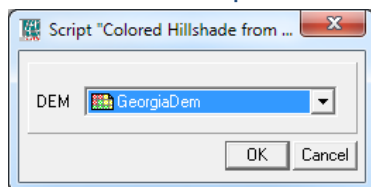
> In the pop-up window, select the complete DEM and select [OK].

The script is executed and the process can be monitored in the "Progress Manager".

At the end of the process the final result is displayed.
The script produced 5 different files:
GeorgiaDem_blue.tiff, GeorgiaDem_green.tiff, GeorgiaDem_red.tiff, GeorgiaDem_Hillshade_color.tiff, GeorgiaDem_Hillshade_color.jpeg.

11.2   BASE MAP CREATION

Add an hill-shading as back-drop image

Expected time: 1 hr
Data: Hillshading produced in Exercise 4.1
   BaseMap of Georgia, Blackboard. (**Master_grey.mxd** and

BaselineData.gdb)

Objectives: After this exercise you will be able to:

Add an hillshading as backdrop-image to a Basemap.

Edit the properties of the hillshading to enhance the image to make it fit for use as a background layer.

The hillshading, produced in the exercise before, will be used to display as BaseMap data. The hillshading will help the user to understand the occurrence of certain types of phenomena or risks. A hillshading is a supportive layer, for that reason the visual strength of it needs to be low. The theme of the map never may be of a visual lower importance then the supporting BaseMap.
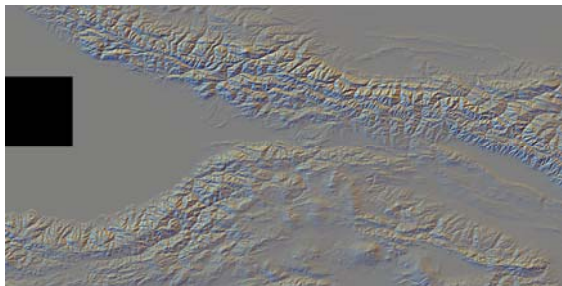
The combined RGB composite.

Below the separate Red Green and Blue intermediates, the DEM exposed from different angles.
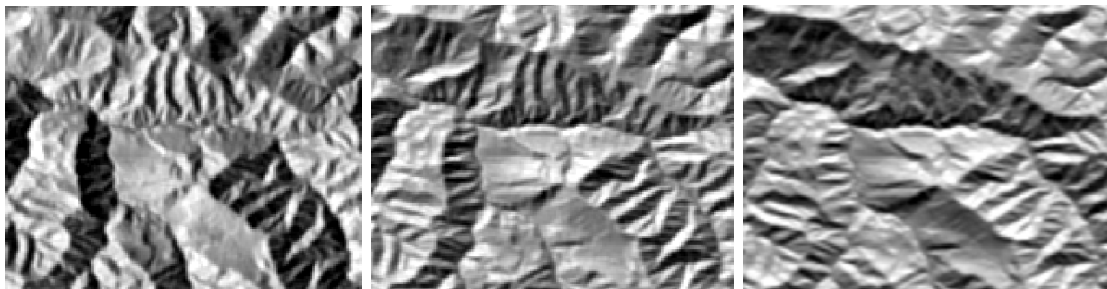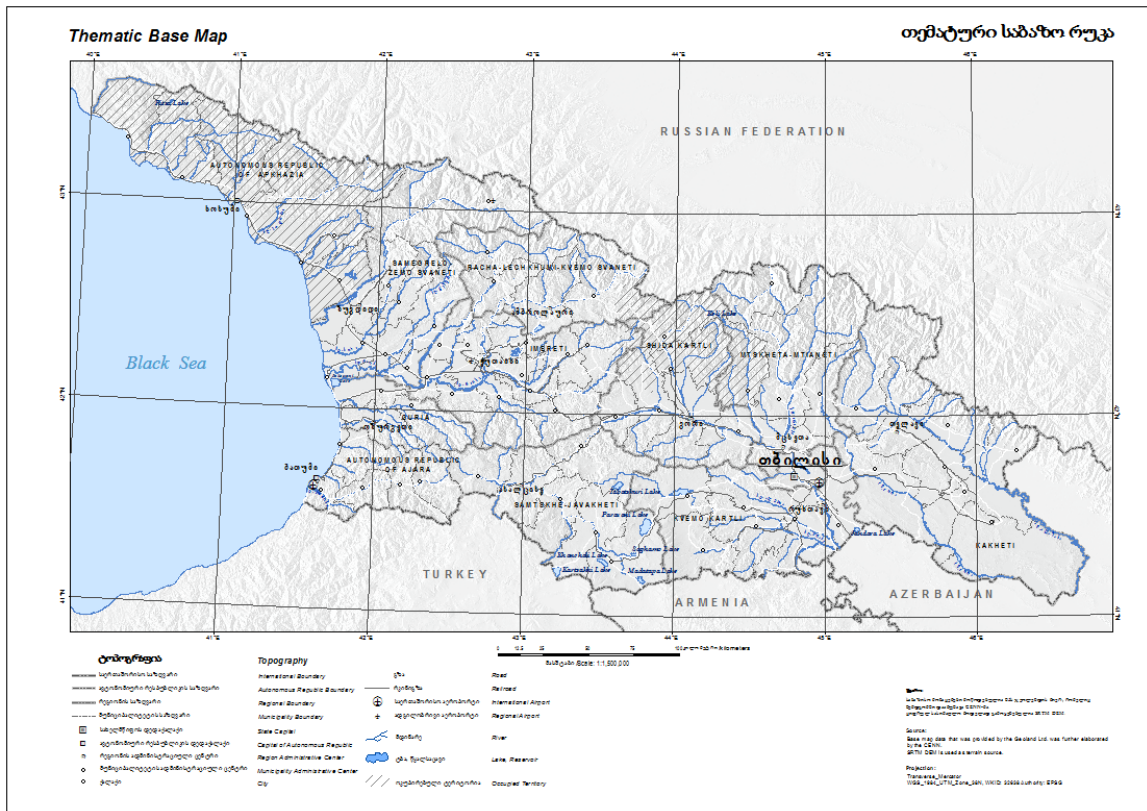

Blue   *green*   *blue*

Base map

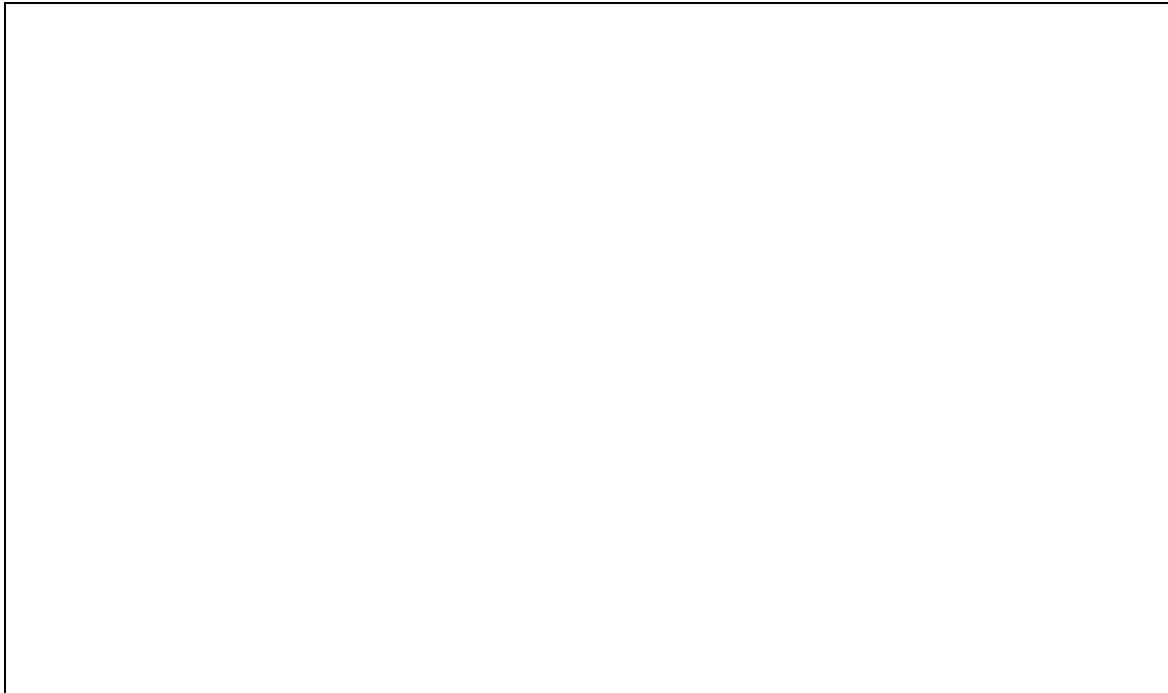The Base-map is preapared and will be explained during the hands-on workshop.

Notes:

Add hillshading and edit properties
The procedure will be explained during the hands-on workshop

Notes:

11.3   EXERCISE "SYMBOL DESIGN AND MAP PRODUCTION"

Expected time: 2 hrs
Data: BaseMap of Georgia, produced in exercise 4.2
      Blackboard. (**Master_grey.mxd** and
      BaselineData.gdb)
      Landslide data (zip file Blackboard)
      Drought data (zip file Blackboard)
      Building exposure (District_points in BaselineData.gdb)

Objectives: After this exercise you will be able to:
      Add thematic data to the Basemap
      Design correct Symbols for the thematic data
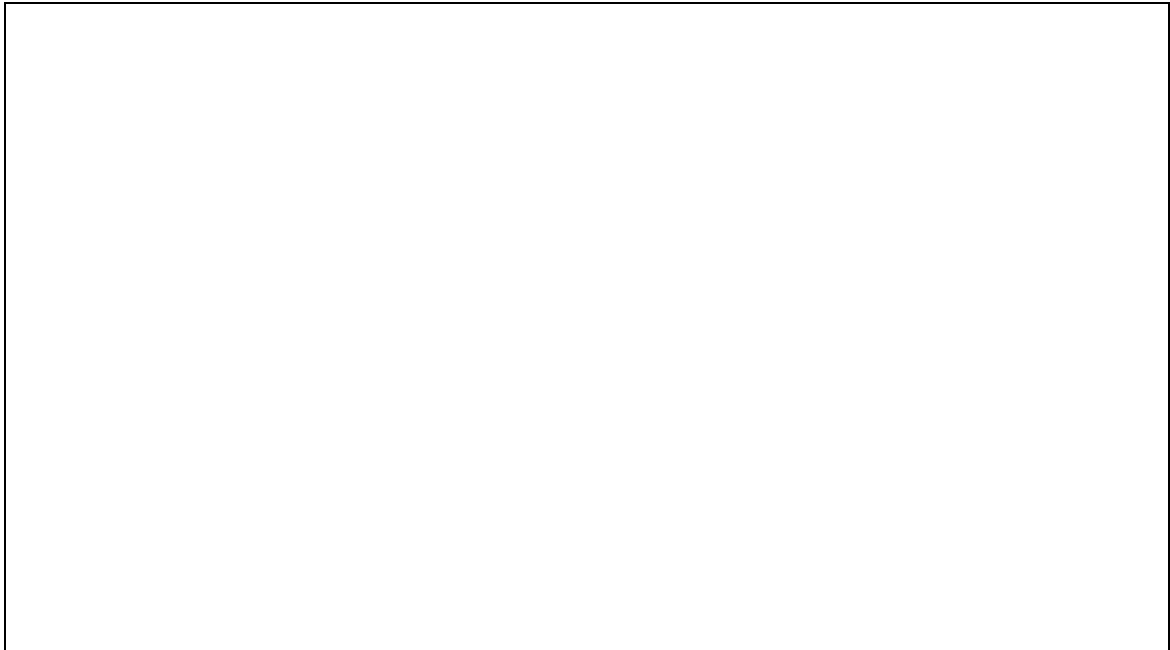   Apply visualization in ArcGis
      Create correct output

Recorded landslides
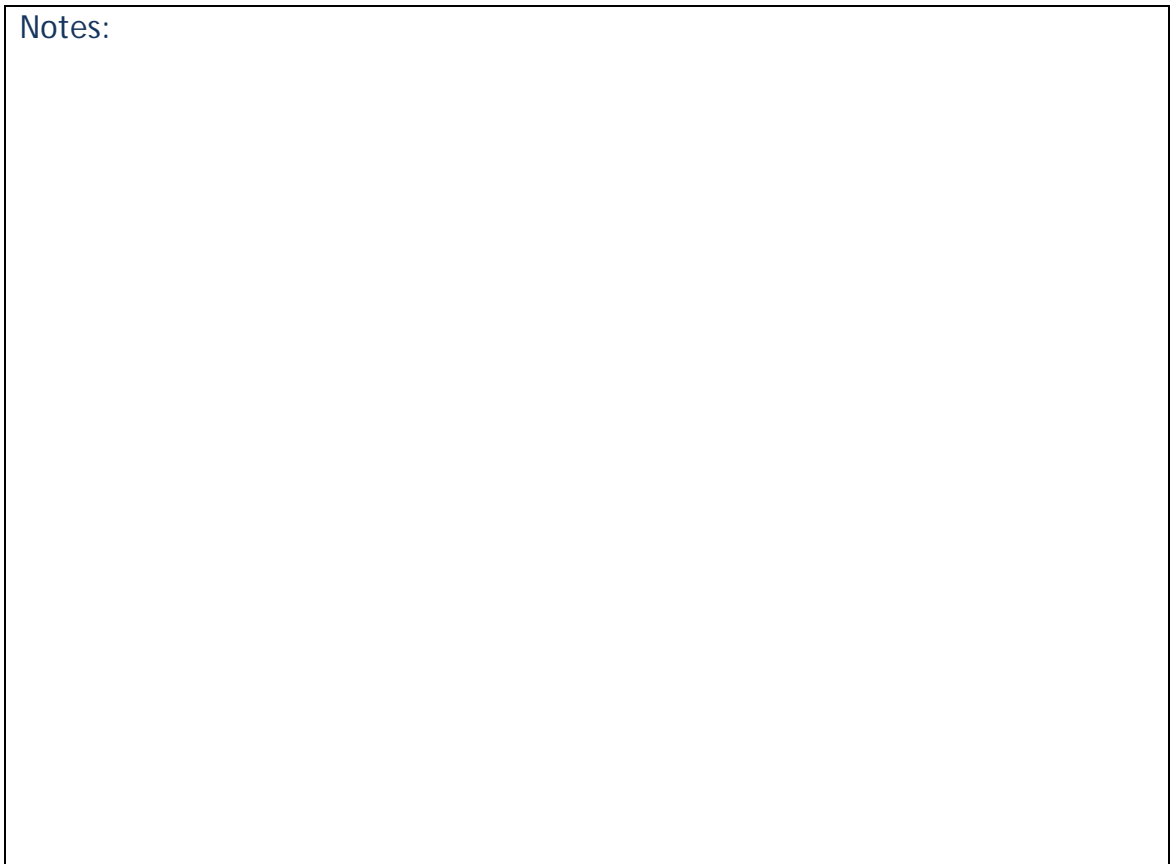The exercises will be further explained during the hands-on workshop.

Notes:

Drought hazard

The exercises will be further explained during the hands-on workshop.

Notes:

Building exposure
The exercises will be further explained during the hands-on workshop.

Notes:

11.4   BASIC WEB-MAPPING EXERCISES

After design and specifications, the actual creation of the Web application can take place.

Creating a WebMapServer Service
In this exercise you will set-up a WebMapService, using MapServer

OpenLayers & OpenStreetMap
This is the exercise description for creating interoperable web map clients using the OpenLayers Javascript API -- Starting with OpenStreetMap

OpenLayers WMS client
This is the exercise description for interoperable web map clients using the OpenLayers Javascript API -- Adding your WMS to an OSM base map

Web Mash up
Building a Mapping Web Site using HTML5, CSS3 and JavaScript APIs