Natural hazard based vulnerability assessment using Spatial Multi Criteria Evaluation

Joan Looijen

(adapted from RiskCity Exercise 5b, by Cees van Westen and Nanette Kingma)

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1 Introduction

The Geo-Information Department of the municipality of RiskCity has prepared a number of hazard maps as part of a risk management plan.
In order to determine the susceptibility of the community of RiskCity to the impact of those hazards and to come up with proper risk reducing measures, the municipality wants to carry out a vulnerability assessment using spatial multi criteria evaluation (SMCE).

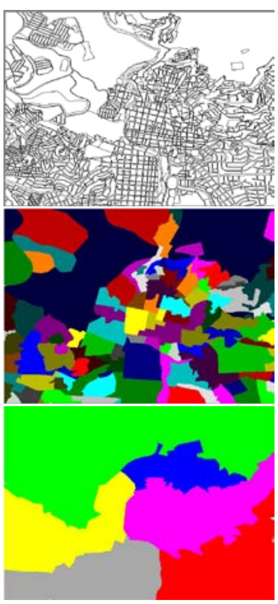
Spatial multi criteria evaluation is a technique that assists stakeholders in decision making with respect to a particular goal, in this case to assess the vulnerability for different natural hazards. It is an ideal tool for transparent group decision making, using spatial criteria, which are combined and weighted with respect to the overall goal. For implementing the analysis in the RiskCity case study, the SMCE module of ILWIS will be used (ITC, 2001). 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 output is one or more maps (so-called 'composite index' maps) indicating the extent to which criteria are met (or not). The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).

1.1 Objectives

In this exercises you will generate a number of indicators for social vulnerability, based on different administrative units. Also indicator maps of physical vulnerability will be generated, as well as some capacity indicators. The social and physical vulnerability indicators are combined with the capacity indicators into an overall vulnerability index using Spatial Multi Criteria Evaluation.
At the end of this exercise you should be able to:

- Define and structure the problem into a main goal and sub-goals
- Define criteria and indicators for each sub-goal
- Generate value functions for each indicator
- Develop and produce different vulnerability maps and scenarios
- Compare the different vulnerability results and point out the most and least vulnerable areas.

1.2 The process



The SMCE process to carry out a vulnerability assessment includes a number of sequential steps. First you have to structure the problem into a main goal (Overall vulnerability assessment) and a number of sub-goals. The main sub-goals identified by the municipality are Social Vulnerability, Population Vulnerability, Physical Vulnerability, and Capacity. For each of these sub-goals a number of objectives and indicators were defined, which measure their performance. Next you will construct for each sub-goal a criteria tree, which represents the hierarchy objectives and indicators. For each of the indicators a link has to be made with the relevant spatial and attribute information. An overview of the objectives and indicators used for each sub-goal is presented in Figure 1.

As the criteria are in different formats (nominal, ordinal, interval etc.) they have to be normalized to a range between 0-1. After standardization, the indicators within a sub-goal are weighted against each other and weights are assigned to the different objectives within a sub-goal. Eventually also weights are assigned to the sub-goals themselves, based on different stakeholder perceptions and expert knowledge, creating different vulnerability scenarios. Once the standardization and weighting is done, a composite index map can be calculated for each sub-goal, and eventually you will produce and evaluate the overall vulnerability map for each scenario.

In general SMCE follows a number of steps:

1. **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.
2. **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.
3. **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.
4. **Weighting of the groups**, in order to come to an overall weight value.
5. **Production of a composite index map (in this case: vulnerability map)**
6. **Classification** of the results.

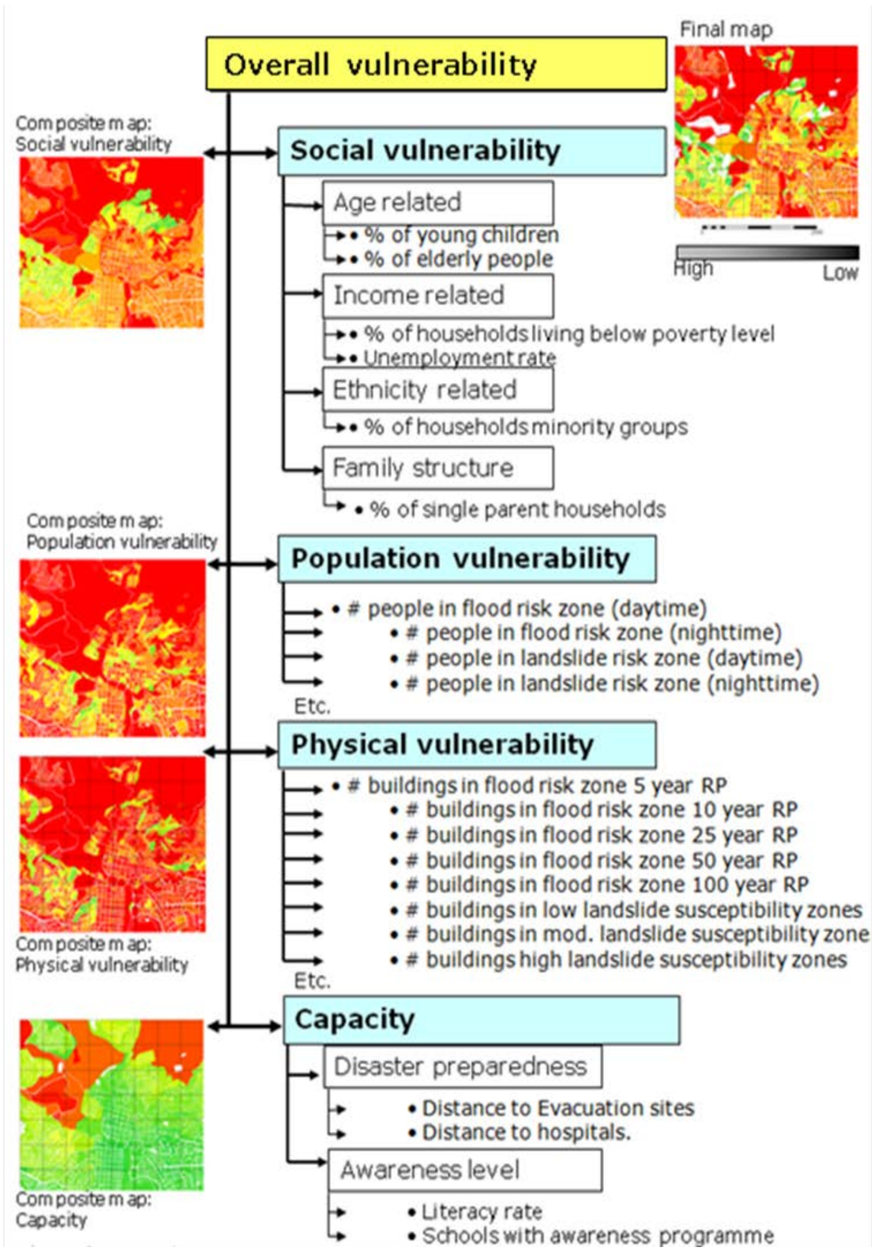


Figure 1 Problem definition: main goal, sub-goals and indicators

2 Structure the problem and data input

2.1 Problem structuring and selection of indicators

Which criteria to use, and how to order them? Which criteria are factors and which ones constraints? This is often one of the most difficult parts of the SMCE procedure and should preferably be decided together with all the relevant stakeholders.
The design of the hierarchical structure of the evaluation criteria, the criterion tree, is the essential part of the SMCE. Before starting the SMCE application you first have to define the main goal (overall vulnerability) and sub-goals, and for each sub-goal the relevant indicators.
In SMCE objectives are translated into one or more clear criteria. For each criterion a corresponding criterion score has to be defined.

The municipality of RiskCity identified four sub-goals:

- To minimize social vulnerability
- To minimize the impact of multi hazards on the community
- To minimize the physical vulnerability
- To maximize capacity (managerial and operational resources and procedures)

To measure the performance of each of these sub-goals a number of specific objectives and indicators have to be defined. This is an important step in the assessment process and is usually done together with relevant stakeholders and experts. An overview of the indicators used for each sub-goal in this exercise is presented in Figure 1 and for two sub-goals in the box below.

Main goal: To minimize the vulnerability of the community of RiskCity for the impact of natural hazards

Sub-goal: To minimize social vulnerability
Objectives
• ***To minimize the loss of people*** (of different age classes)
% of young children
➤ % of people of primary school age
➤ % of people of secondary school age
➤ % of adolescents following further education
➤ % of population in working age
➤ % of retired people

• ***To minimize loss of income***
➤ % of population living below the poverty level
➤ unemployment rate

• ***To minimize ethnical impacts***
➤ % of population coming from minority groups

• ***To minimize the disruption of the social structure***
➤ % of single households

Sub-goal: To minimize the impact of multi hazards on the community
Objectives
• To minimize the number of people affected by earthquakes (during day and night time)
• To minimize the number of people affected by landslides (during day and night time)
• To minimize the number of people affected by flooding (during day and night time)
• To minimize the number of people affected by pool fires and explosions (during day and night time)

Sub-goal: To minimize the physical vulnerability'
Objectives
• To minimize the loss of buildings by earthquakes
• To minimize the loss of buildings by landslides
• To minimize the loss of buildings by flooding
• To minimize the loss of buildings by pool fires and explosions

Sub-goal: To maximize capacity'
Objectives
• To minimize the distance to emergency centres
➤ distance to hospitals
➤ distance to police stations
➤ distance to fire stations

• To maximize disaster awareness
➤ Literacy rate of the population

RISK = HAZARD * VULNERABILITY * CAPACITY

In this exercise we are using the Risk relation as indicated in the formula on the left. We would like to include both vulnerability as well as capacity. Capacity expresses the positive managerial and operational resources and procedures for reducing risk factors.

2.2 Input data

In the RiskCity case study the vulnerability and capacity indicators are linked to three different spatial levels: mapping units, wards, and districts within the city (see table 1 for a general overview). The data needed for this exercise is stored in a number of tables that can be linked to the polygon and raster maps of the three different administrative levels: **Mapping_units** (the smallest subdivision which are mostly building blocks surrounding by streets), **Wards** (neighborhoods of the city) and **Districts** (the whole city, which is composed of 5 districts).
These three different administrative units also have different attribute information related to it. For example, demographic information from the city is only available at a generalized district level. Unemployment information is available at ward level, whereas information on poverty level and social structure is available even at building block level.

> There is also a fourth level, which is the level of individual buildings (map Building_map). However, at this level we don't have any relevant information that can be used as indicators in the SMCE process.

Table 1 General overview of data used in this exercise.

Name	Type	Meaning
Elements at risk		
Mapping_units	Polygon	Building blocks of the city
Mapping_units	table	Table containing general statistical information on the number of buildings and people per building block
Wards	Polygon	Ward of the city
Wards	Table	Table with population information derived from census data for the wards in the city
Districts	Polygon	Districts of the city
Districts	Table	
Losses for different types of hazards		
Flood_risk_buildings **Seismic_risk_buildings** **Technological_risk_buildings** **Landslide_risk_buildings**	Tables	Tables with the results of the loss estimations for flooding, earthquakes, landslides and technological hazards for buildings. These are the results of the previous exercises
Flood_risk_population **Seismic_risk_population** **Technological_risk_population** **Landslide_risk_population**	Tables	Tables with the results of the loss estimations for flooding, earthquakes, landslides and technological hazards for buildings. These are the results of the previous exercises
Other data		
High_res_image	Raster	High resolution image of the study area.

A more detailed overview of available data for Social vulnerability assessment are shown in Annex 1, for population vulnerability in Annex 2, for Physical vulnerability in Annex 3 and for Capacity in Annex 4.

3 Procedure

The SMCE module of ILWIS-GIS was used to assess the vulnerability of people and assets to natural hazards. The SMCE application assists and guides users when performing multi-criteria evaluation in a spatial manner (ITC, 2001). 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 semi-quantitative model implemented (Figure 2). The theoretical background for the multi-criteria evaluation is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980).

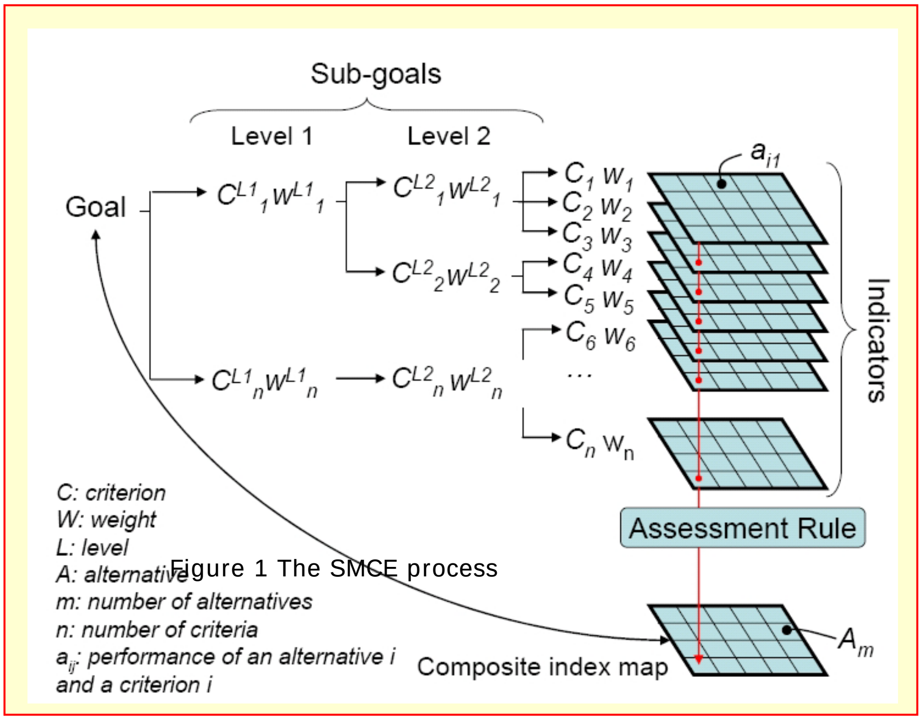


Figure 1 The SMCE process

Figure 2
The SMCE process

You will follow a number of steps which are schematically indicated below. You are structuring the main groups of indicators in *Generic Social Vulnerability Indicators*, *Hazard specific Social vulnerability indicators*, *Hazard Specific Physical Vulnerability Indicators*, and *Capacity Indicators*. Then the following steps are needed:

- **Step 1**: Generation in SMCE of a criteria tree for **Generic Social Vulnerability Indicators**, with the groups of factors, the standardization of the factors and definition of weights using pair wise comparison (section 5).
- **Step 2**: Generation in SMCE of a criteria tree for **Hazard specific social vulnerability indicators**, with the groups of factors related to population affected by earthquakes, landslides, flooding and technological disasters in a daytime, and night-time scenario, the standardization of the factors and definition of weights using pair wise comparison (section 6).
- **Step 3**: Generation in SMCE of a criteria tree for **Hazard specific physical vulnerability indicators**, with the groups of factors related to buildings affected by earthquakes, landslides, flooding and technological disaster scenarios, the standardization of the factors and definition of weights using pair wise comparison (section 7).
- **Step 4:** Generation in SMCE of a criteria tree for **Capacity indicators**, which in this case is limited to only one: the level of awareness (section 8).
- **Step 5**: Combination of the 4 sets of indicators into an **overall vulnerability indicator** (section 9).

Note: it is also possible to carry out the steps independently and also to skip one or more. If you are working in a group these topics could be done by individual team members.
It is also possible to carry out the full analysis in one criteria tree (Figure 3). However, we advise to do it in the individual components described above.

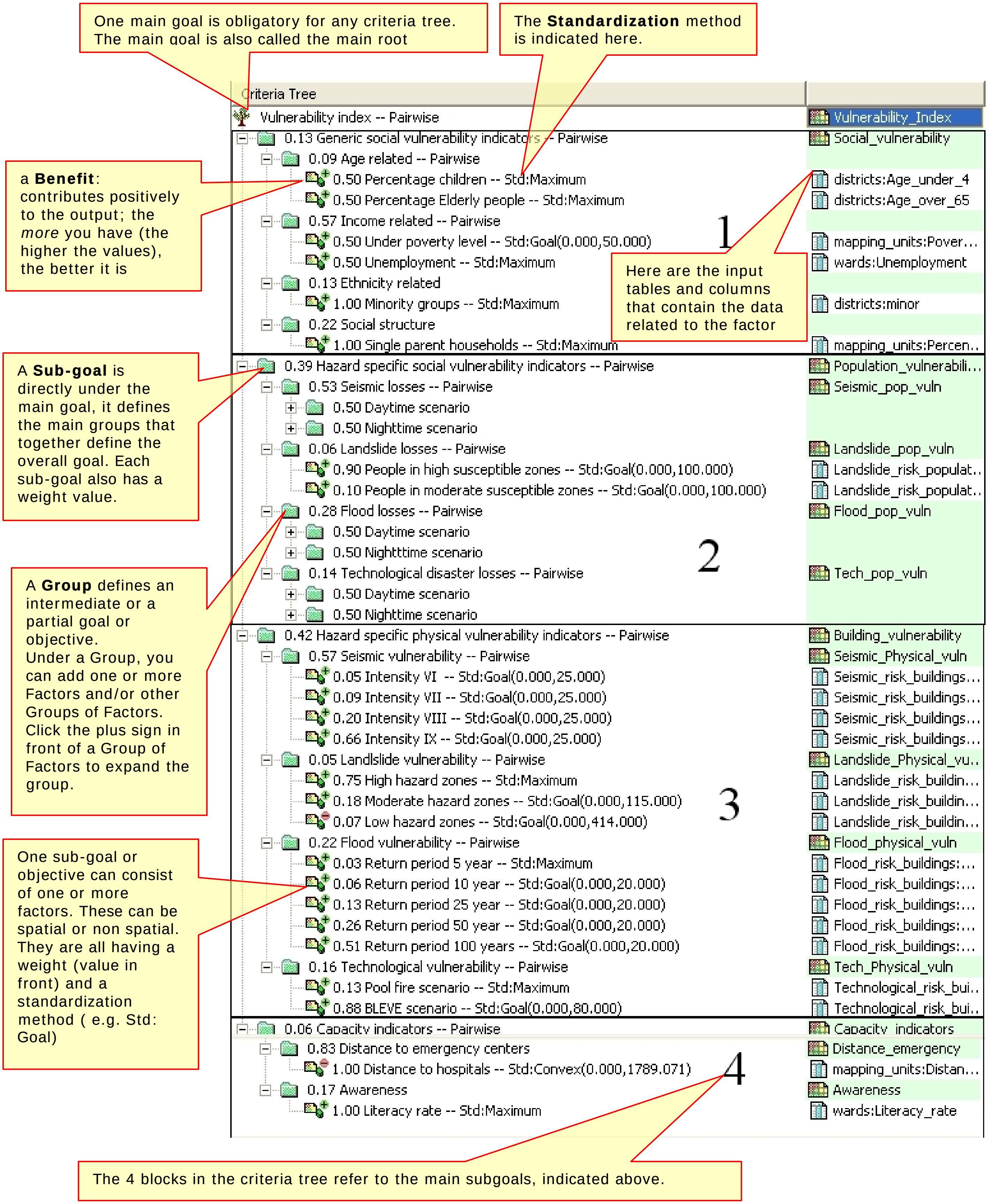


Figure 3 Example of a criteria tree for the overall vulnerability assessment.

4. Getting started

Make a new sub-directory SMCE-vulnerability on your working directory. Copy the data belonging to this exercise to this sub-directory SMCE-vulnerability.

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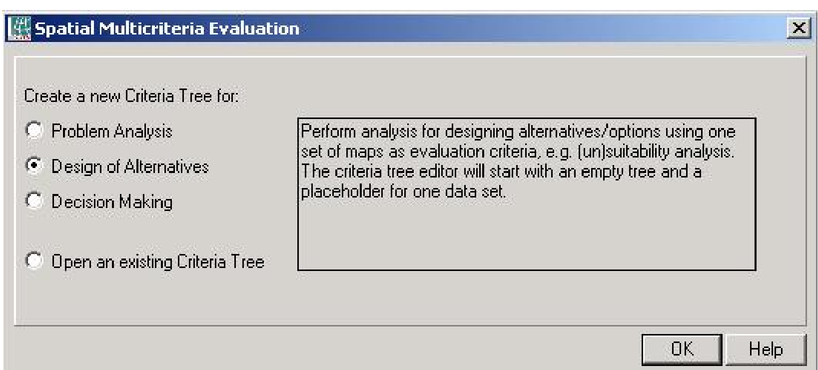
- Double-click the ILWIS program icon.
- Change the working drive and the working directory until you are in the directory 'SMCE'
- Start the Spatial Multi-Criteria Evaluation operation, choose Raster Operations, Spatial Multi-Criteria Evaluation from the Operations menu in the Main window, or expand 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;
  Analyse 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.
  The Number of Alternatives dialog box will follow, in which you can specify the number of alternatives and the names for the alternatives, e.g. in environmental impact assessment. Decide between alternatives/options using a set of maps for each alternative as evaluation criteria (Effect table). The criteria tree editor will start with an empty tree and placeholders for a number of data sets, each corresponding to an alternative. By default, the number of alternatives is two.

You can also open an existing criteria tree.



By default the option Design of Alternatives is highlighted. You can select this option when you will later on formulate and assess alternative locations for waste disposal (optional). You can also start with Problem Analysis, and later on continue with the Design of alternatives.

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- Select Problem Analysis or Design of Alternatives.
- Press OK.

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

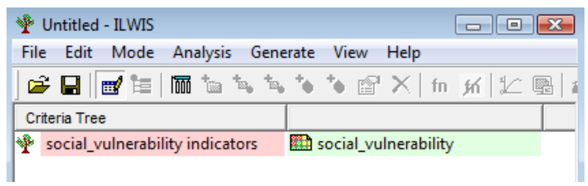
- ***Title bar*** with the name of the criteria tree (By default: 'New Goal')
- ***Menu bar***. The SMCE window has seven menus, File, Edit, Mode, Analysis, Generate, View and Help.
- ***Toolbar***, by default located just below the menu bar. The toolbar provides shortcuts for some regularly used menu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

4.1 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. 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.



4.2 Constructing the criteria tree

You will always start with 'Creating a criteria tree'. Note that the 'Problem Definition mode' is highlighted. 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	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.

5 Social vulnerability indicators

Step by step we will take you through the procedure to generate a generic social vulnerability index using the ILWIS Spatial Multi Criteria Evaluation (SMCE) software tool. We assume that you have some basic knowledge on SMCE, and will not explain a lot on the background. Please consult the ILWIS help if you need more information.

5.1. Problem definition and construction of the criterion tree

In this step you will construct a criteria tree for the social vulnerability indicators using the Problem definition mode of ILWIS-SMCE. For each indicator (spatial factor) you will include the corresponding spatial data.

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- 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:

  Social_Vulnerability_indicators, and the name of the output map (in the right side) to **Social_Vulnerability**.
- Right click on **Social_Vulnerability_indicators** and select *Insert group*. Add the groups: **Age_related**, **Income related**, **Ethnicity related**, **Social Structure Related**.
- Include for each group the various factors for the individual criteria, as indicated in figure 4 by right-clicking on the individual criteria and inserting the spatial factors; or use the 'insert spatial factor' icon.

QUESTION: Apart from the criteria that are given here, which other indicators do you think could be used in determining social vulnerability? Name a few examples, and indicate where you could get such data from, in your own country.

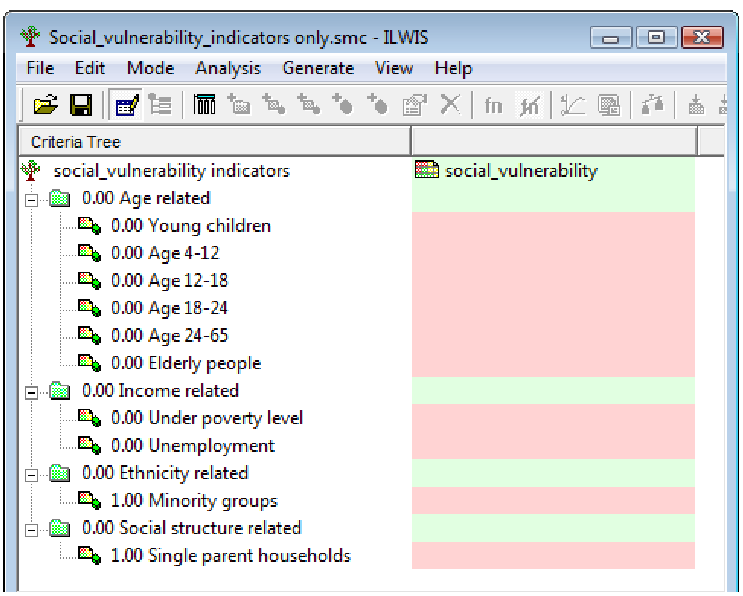

Figure 4 Criterion tree with social vulnerability criteria and indicators (factors)

Adding spatial data

Next you will have to assign the spatial data for each of the spatial factors that you have defined. These are all coming from tables, linked to the map **Mapping_units**.
Note: red areas in SMCE mean that data is still not defined.

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- Double click on the red area next to **Young children**. Select from the map **Mapping_units** the column: **Age_under_4**.
- Find also the relevant spatial information for the other criteria, and the result is indicated below in Figure 5.
- Save the criteria tree as **Social_vulnerability.**

Adding output map names

In ILWIS-SMCE you can produce an output map at the level of the goal, but also at the level of sub-goals (groups of indicators).

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- Double-click in the green area next to 'Age related' and fill in Age_related; Press enter.
- Do the same for Income related, Ethnicity related and Social structure related

QUESTION: What is the advantage to present not only the overall social vulnerability map, but also the intermediate maps at the level of the sub-goals?

When finished, your criteria tree should look like the example shown in figure 5 below.

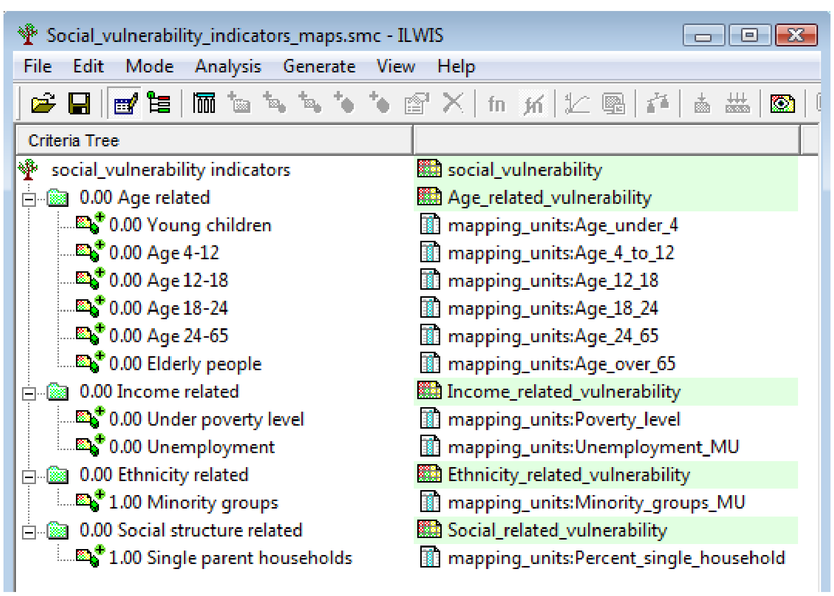

Figure 5 Criterion tree with social vulnerability criteria, indicators (factors) and corresponding spatial data

Note: all parts indicated in red should be completed before you can start the multi criteria analysis.

5.2. Standardization of the factors

In this case all the factors used in the social vulnerability assessment are of the "value" type, and they are all stored as attributes in an attribute table linked to one map. 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. Standardization is part of the Multi Criteria Analysis mode in ILWIS-SMCE.

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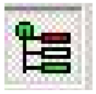
- In the SMCE window, change the Mode from "*Problem Definition*" to "*Multi Criteria Analysis*". Now you can start standardization.
- Double click on the red area indicating **0.00 Young children**. A window opens in which a graph is shown fitting the data range of values for this factor over the range of 0-1.



You have the option to select several ways of scaling the values between 0 and 1. The box below shows the various standardization methods.

How to standardize?
You have to define yourself the ranges between which 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 value 1 (highly vulnerable).
These threshold values are often defined in a group decision making process through workshops etc. In a class room you can discuss these values with your neighbours.

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 a specified maximum and minimum value
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 Gaussian-Bell-shape curve with one user defined value to stretch or shrink the curve (under Combination)

When selecting the boundaries for standardization, you always have to consider the aim of the standardization procedure (in this case social vulnerability), and how this particular indicator is related to that. In this case: the higher the percentage of children in an area, the higher the vulnerability of the population. In terms of SMCE this would be a benefit, to determine the direction of the graph. You can use a simple straight line, between 0 and the maximum value. In maximum standardization all values will be divided by the maximum. In other cases there will be a maximum value above which you will always find the vulnerability high. E.g. for the estimation of the population losses, you could say that any loss above 10 is high, and should be 1. In that case you select the Goal option, and you can adjust the values manually. This type of threshold values may come from official regulations (targets), expert knowledge and/or stakeholder consultations.

Benefit: The higher the value, the higher the vulnerability
Cost: The higher the value, the lower the vulnerability

QUESTION: Which of the indicators in Figure 1 represent a cost function?

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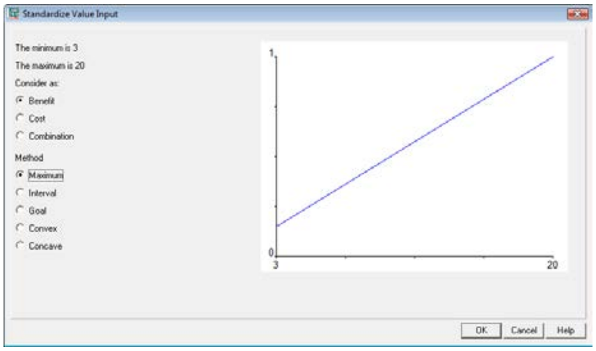
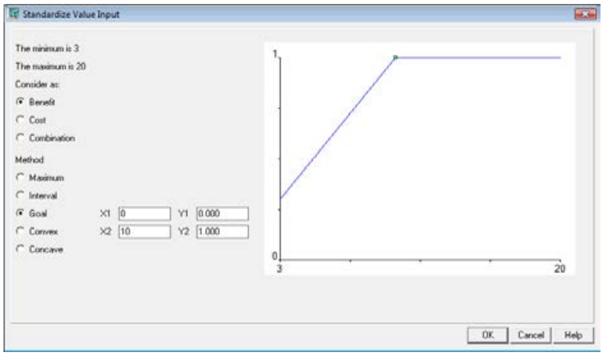
- Open the standardization window for the factor **Elderly people**
- Select the goal option and change the minimum X to 0 and the maximum to 10.
- Standardize the other indicators using appropriate value functions.

Compare the graphs below for the factor Elderly people to understand the difference between a maximum standardization function and using a goal function with a threshold value of 10.





QUESTION: How much is the vulnerability value if 3 elderly people die?

Maximum:

Goal:

After standardizing all factors, your criteria tree will look like the one below in Figure 6. The red bars are indicating the places where you need to assign weights.

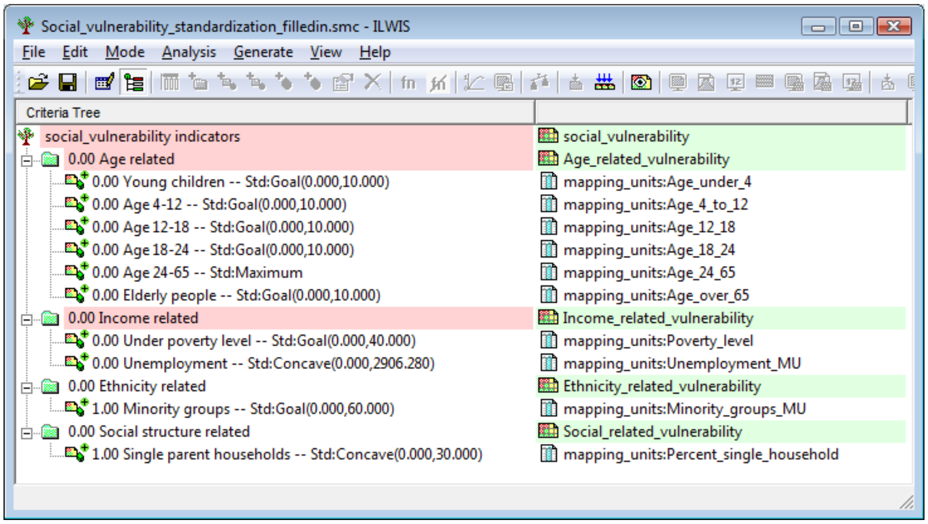


Figure 6 Standardized criterion tree for social vulnerability

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- To see the result of the standardization: Right click on the name **Young children** and select *Show standardized*. A map opens that contains the standardized values.
- Open *PixelInformation* in the map you just created and add the map Mapping_units, which is linked to the table **Mapping_units**. Compare the original values to the standardized values.

QUESTIONS:

- Why is a maximum standardization used for the indicator Age_24-65 and not a goal function with a threshold of 10 people?
- Why is a concave value function used for the indicators Unemployment and Single parent households in the criterion tree of Figure 6 and what is the meaning?

5.3. Assigning weights

Once all the criteria are standardized, the relative importance of the different criteria and group of criteria has to be defined in order to determine the overall performance of each pixel. This can be between the factors in the same group (e.g. the two factors "*Young_children*" and "*Elderly_people*" in the group "*Age related*"), or the weights among the groups (e.g. "*Age related*" versus "*Income related*"). There are two groups that have only one factor, and therefore the weights for these two are 1 (see above: "*Minority groups*", and "*Single parent households*").
In this step expert knowledge and the viewpoints of stakeholders play an important role again.

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.
- The sum of the weights among groups is also 1.
- Constraints are not considered during weighing.

For the determination of weights in SMCE you can 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), and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights).

In this exercise you will work mostly with pairwise comparison.

Assigning weights to factors within a group

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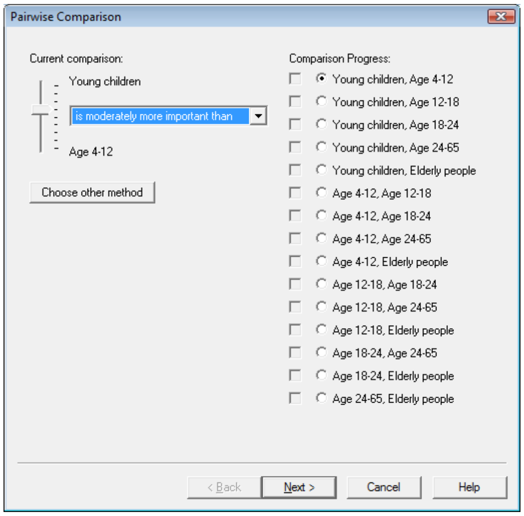
- Right-click the red indicated factor group "***Age related***", and select Weight (or use the 'weighting icon'). Select the option: *Pairwise*)see Figure 7a).
- Determine whether for the determination of social vulnerability, the percentage of young-children is more important than the percentage of elderly people, or equal, or less. Discuss this with your neighbors / group members.
- Enter all the weights to factors within the four groups.
- Save the criterion tree.

The criteria tree will then look like the one in Figure 7b.



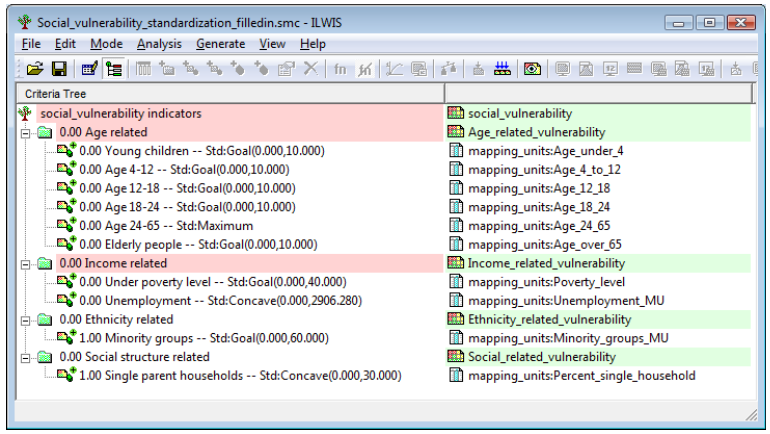


Figure 7a Example of pairwise comparison

Figure 7b Criterion tree with weights assigned to factors within a group

Determining the weights among groups

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

Different scenarios can be simulated by giving more or less importance to a particular group of factors. For example, some stakeholders may put more emphasis on the 'social structure' related indicators, while others find age related factors more important, or income related.

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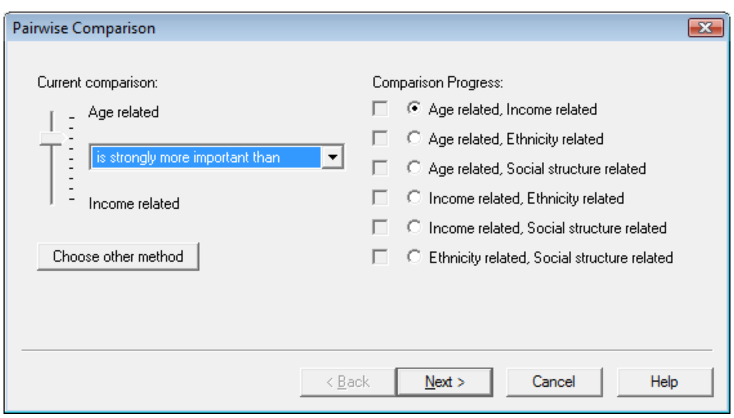
- Right-click the red indicated upper line "*Social vulnerability indicators*", and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance (see below). Discuss this with your neighbours / group members.



The resulting criteria tree might look like the one below in Figure 8 (but the weights could be different, depending on the importance you gave to the different factors and groups of factors).

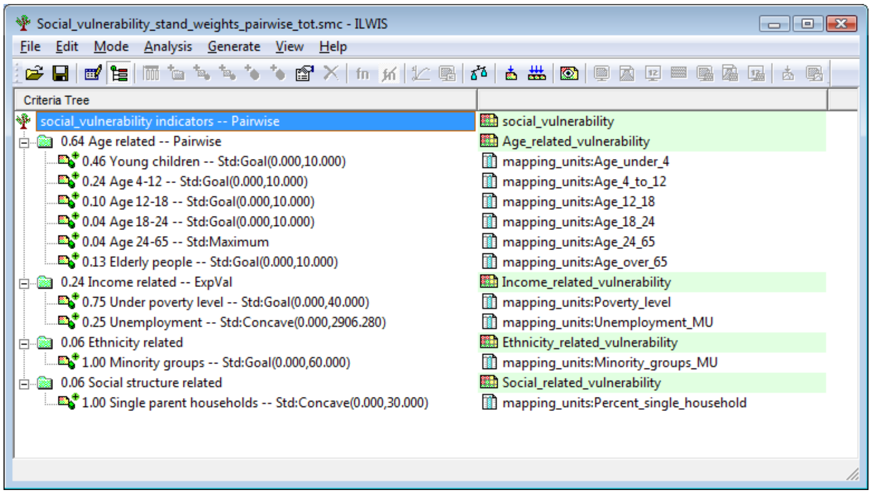


Figure 8 Standardized and weighted criterion tree

QUESTIONS:

- Which group of indicators got the highest importance (weight) in the example of Figure 8 and which group the lowest?
- Would you give the same priorities to these groups of indicators? If not, propose another weight assignment and explain your choice.

5.4 Vulnerability mapping

Once all the indicators are standardized and weighted you can calculate the output map, in this case the social vulnerability map.

☞

- Right-click the map icon "**Social_vulnerability**", and select Generate selected item.
- Display the result map.
- Use *PixelInfo* to compare the overall vulnerability map with the four sub-goal maps.
- You can adjust the standardization and/or weights if you would like to make adjustments. Save those adjustments under a different criterion tree name and also give different names to the output maps (if you want to keep the original ones).

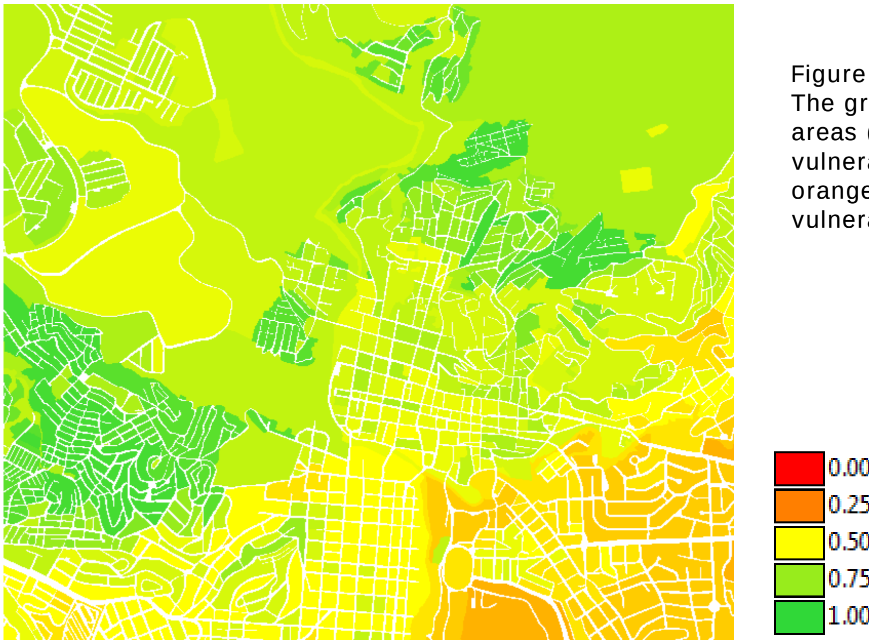


Figure 9 Social vulnerability map. The green colours represent areas (pixels!) with a high vulnerability and the red and orange colours areas with a low vulnerability.

QUESTIONS

- What can you conclude from the pattern of social vulnerability?
- Which indicators contribute most to the overall social vulnerability?

6. Hazard specific population vulnerability indicators

This part of the vulnerability assessment will not be done during the course, but you will get the final result to be able to prepare an overall vulnerability map in the end.
The criteria tree with the population vulnerability indicators and the resulting population vulnerability map are shown in figure 10 and 11 respectively. The population that might be affected by earthquakes, landslides, flooding and technological disasters during a day-time and night-time scenario were combined into one population vulnerability.

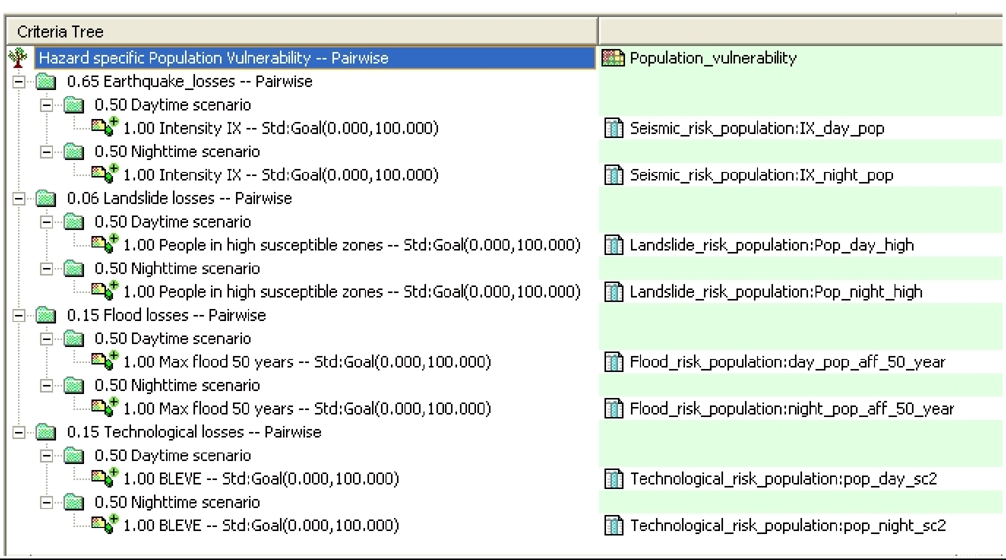


Figure 10. Criterion tree for population vulnerability

QUESTIONS

- What value function was used for the different indicators?
- Was any threshold used and if so, which value?
- Do you agree with this threshold? If not, propose another threshold and explain your choice.
- Which hazard was considered most important for loss of population?

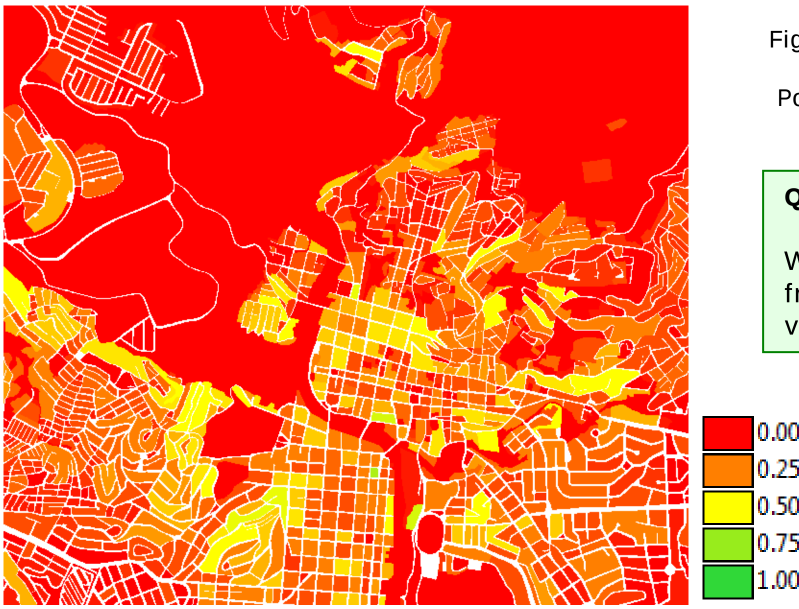


Figure 11.

Population vulnerability map

QUESTION

What can you conclude from the pattern of population vulnerability?

7. Hazard specific physical vulnerability indicators

In this part you will generate the maps required for the hazard specific physical vulnerability indicators using SMCE. Assumed is that the procedure for estimating the number of buildings that might be affected by earthquakes, landslides, flooding and technological disasters is known. Here we will combine them into one physical vulnerability index.

7.1 Problem definition and construction of the criterion tree

☞

- Select *Operations / Raster Operations / Spatial Multi Criteria* Evaluation. Select the option Problem Analysis. An empty problem tree is opened.
- Save the new criteria tree as **Physical_Vulnerability**, and give the goal and output file the same name (right click select Edit, or double click).
- Right click on the goal **Physical_Vulnerability** and select *Insert group*. Add groups of the individual groups of factors: **Seismic Vulnerability, Landslide Vulnerability, Flood Vulnerability** and **Technological Vulnerability**.
- Include for each hazard type the indicators, in this case all the calculated scenarios for each hazard type. For example, for earthquakes, add scenarios VI, VII, VIII and IX intensity. Right click e.g. on the group **Earthquake Vulnerability** (or use the 'insert spatial factor' icon) and add the first factor ' Intensity_VI'.

Your criteria tree should like the one in Figure 12 below

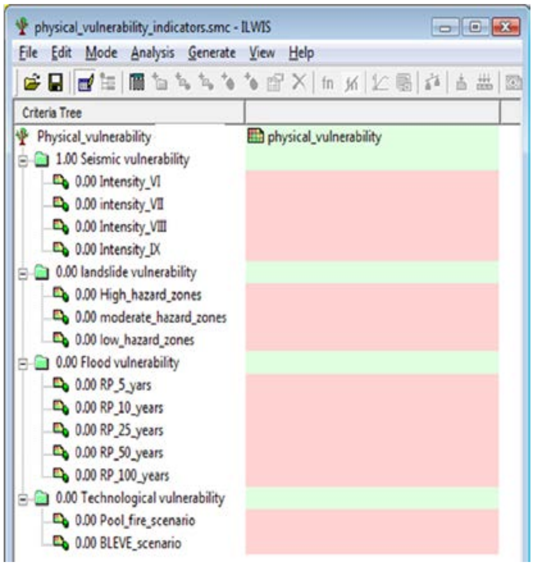


Figure 12 Criterion tree with physical vulnerability criteria and indicators (factors)

QUESTION: Apart from the criteria that are given here, which other indicators do you think could be used in determining physical vulnerability? Name a few examples, and indicate where you could get such data from, in your own country.

Adding spatial data

Next you will have to include the spatial data that for each of the spatial factors that you have defined. These are all coming from tables, linked to the following maps: Seismic_risk_building, Landslide_risk_building, Flood_risk_buildings and Technological_risk_buildings.
Note: red areas in SMCE mean that data are not included yet.

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- Double click on the red area next to **Intensity VI**. Select from the map Seismic_risk_building the column: Intensity VI
- Find also the relevant spatial information for the other criteria, and the result is indicated below in Figure 13. Note that for the 'Pool_fire_scenario' of the group 'Technological vulnerability' you have to add the attribute column 'Nr_buildings_sc1' of the map 'Technological_rsik_buildings'; for the 'BLEVE_scenario' you have to add 'Nr_buildings_sc2'.
- Save the criteria tree Physical_vulnerability.

Adding output map names

In ILWIS-SMCE you can produce an output map at the level of the goal, but also at the level of sub-goals (groups of indicators).

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- Double-click in the green area next to 'Seismic vulnerability' and fill in Seismic_ vulnerability; Press enter.
- Do the same for Landslide Vulnerability, Flood Vulnerability and Technological Vulnerability

QUESTION: What is the advantage to present not only the overall physical vulnerability map, but also the intermediate maps at the level of the sub-goals?

When finished, your criteria tree should look like the example shown in figure 13 below.

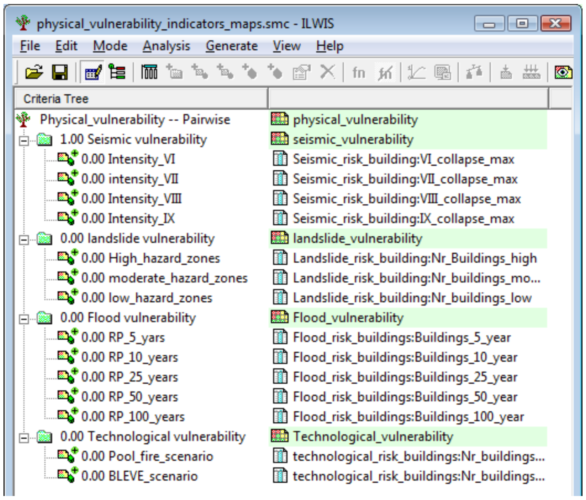

Figure 13 Criterion tree with social vulnerability criteria, indicators (factors) and corresponding spatial data

Note: all parts indicated in red should be completed before you can start the multi criteria analysis.

7.2. Standardization of the factors

In this case all of the factors used in the physical vulnerability assessment are of the "values" type, and they are all stored as attributes in an attribute table linked to a map. 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.

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- In the SMCE window, change the Mode from "*Problem Definition*" to "*Multi Criteria Analysis*". Now you can start standardization.
- Double click on the red area indicating **Intensity_VI**. A window opens in which a graph is shown fitting the data range of values for this factor over the range of 0-1.

You have the option to select several ways of scaling the values between 0 and 1. The box on the right shows the various standardization methods.

How to standardize?
You have to define yourself the ranges between which 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 value 1 (highly vulnerable).
These threshold values are often defined in a group decision making process through workshops etc. In a class room you can discuss these values with your neighbours.

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 a specified maximum and minimum value
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 Gaussian-Bell-shape curve with one user defined value to stretch or shrink the curve (under Combination)

When selecting the boundaries for standardization, you always have to consider the aim of the standardization procedure (in this case physical vulnerability), and how this particular indicator is related to that. In this case: the higher the risk a building collapses due to an earthquake, the higher the vulnerability of the community living in that area. In terms of SMCE this would be a benefit, to determine the direction of the graph. You can use a simple straight line, between 0 and the maximum value. In maximum standardization all values will be divided by the maximum. In other cases there will be a maximum value above which you will always find the vulnerability high. E.g. for the estimation of the loss of buildings, you could say that any loss above 25 is high, and should be 1. In that case you select the Goal option, and you can adjust the values manually. This type of threshold values may come from official regulations (targets), expert knowledge and/or stakeholder consultations.

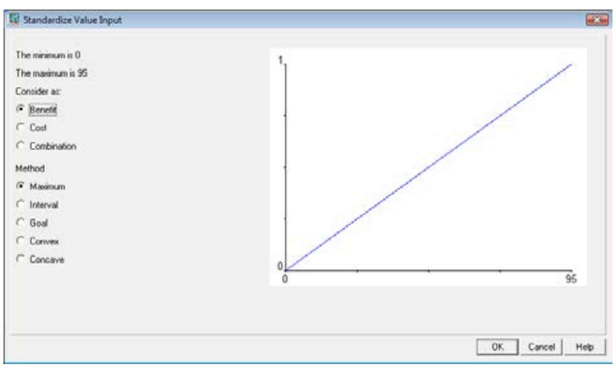
Benefit: The higher the value, the higher the vulnerability
Cost: The higher the value, the lower the vulnerability

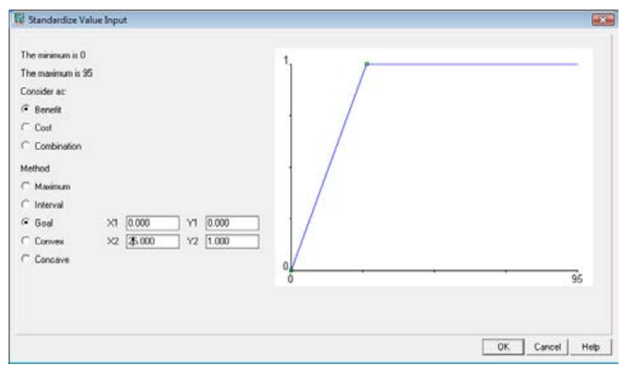
QUESTION: Which of the indicators in Figure 1 represent a cost function?

☞

- Open the standardization window for the factor **Intensity_VI**
- Select the goal option and change the minimum X to 0 and the maximum to 25.
- Standardize the other indicators using appropriate value functions.

Compare the graphs below for the factor Intensity_VI to understand the difference between a maximum standardization function and using a goal function with a threshold value of 25.





QUESTION: How much is the vulnerability value if 50 buildings collapse?

Maximum:

Goal:

After standardizing all factors, your criteria tree will look like the one below in Figure 14. The red bars are indicating the places where you need to assign weights.

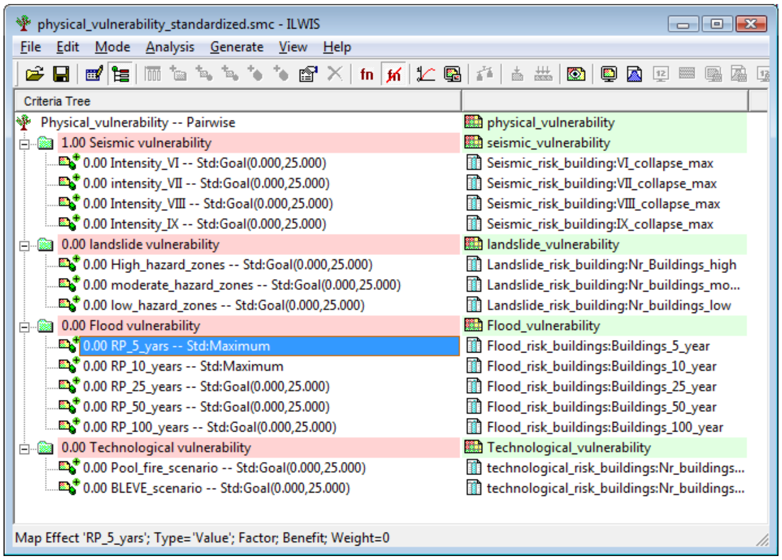


Figure 14 Standardized criterion tree for physical vulnerability

QUESTIONS:

Why is maximum standardization used for the indicators RP_5_years and RP_10_years (return period of 5, respectively10 years) and not a goal function with a threshold of 25 buildings?

All other factors were standardized using a goal function with a threshold of 25 buildings. Do you agree? If not, propose another threshold value and explain your choice.

☞

- To see the result of the standardization: Right click on the name **Intensity_VI** and select *Show standardized*. A map opens that contains the standardized values.
- Open *PixelInformation* in the map you just created and add the map Seismic_risk_building, which is linked to the table **Seismic_risk_buildings**. Compare the original values to the standardized values.

7.3. Assigning weights

Once all the criteria are standardized, the relative importance of the different criteria and group of criteria has to be defined in order to determine the overall performance of each pixel. This can be between the factors in the same group (e.g. the two factors "*Intensity_VI*" and "*earthquake_IX*" in the group "*Seismic vulnerability*"), or the weights among the groups (e.g. "*Seismic vulnerability*" versus "*Flood vulnerability*").
In this step expert knowledge and the viewpoints of stakeholders play an important role again.

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.
- The sum of the weights among groups is also 1.
- Constraints are not considered during weighing.

For the determination of weights in SMCE you can 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), and
- **Rank ordering** (you indicate the relative ranking of the factors, and the software converts these in quantitative weights).

In this exercise you will work mostly with pairwise comparison.

Assigning weights to factors within a group

☞

- Right-click the red indicated factor group "***Seismic vulnerability***", and select Weight (or use the 'weighting icon'). Select the option: *Pairwise* (see Figure 15a)
- Determine whether for the determination of physical vulnerability, scenario VI is more important than scenario VII, or equal, or less. Discuss this with your neighbours / group members.
- Enter all the weights to factors within the four groups.
- Save the criterion tree.

The criteria tree will then look like the one in Figure 15b.

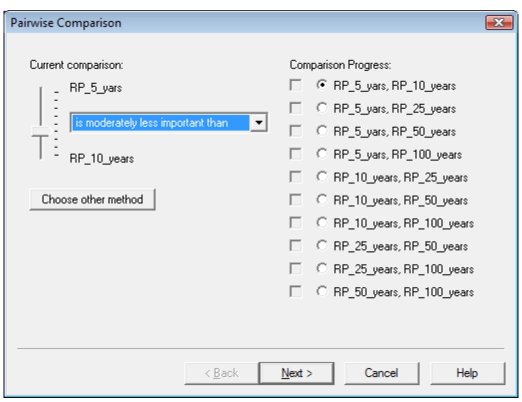


Figure 15a Example of pairwise comparison

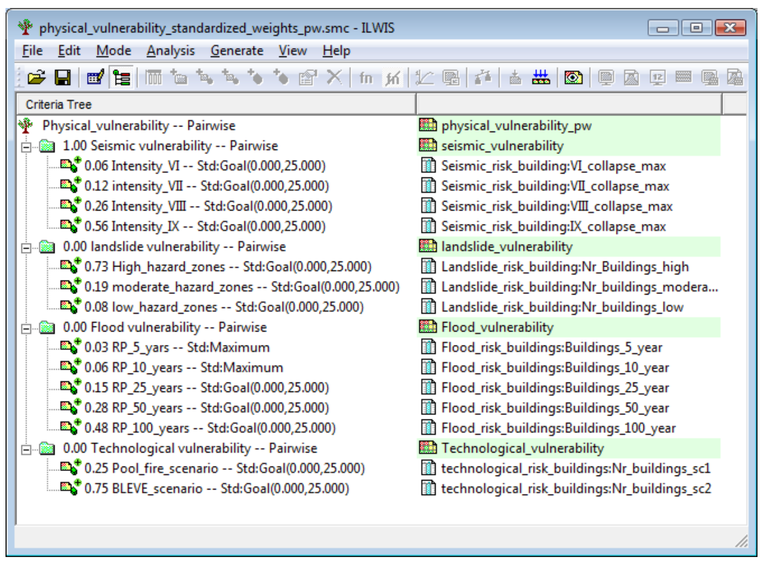


Figure 15b Criterion tree with weights assigned to factors within a group

Determining the weights among groups

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

Different scenarios can be simulated by giving more or less importance to a particular group of factors. For example, some stakeholders may put more emphasis on the 'social structure' related indicators, while others find age related factors more important, or income related.

☞

- Right-click the red indicated upper line "*Seismic vulnerability*", and select Weight. Select the option: *Pairwise*
- Determine for each combination the relative importance. Discuss this with your neighbours / group members. .

The resulting criteria tree might look like the one in Figure 16 (but the weights could be different, depending on the importance you gave to the different factors and groups of factors).

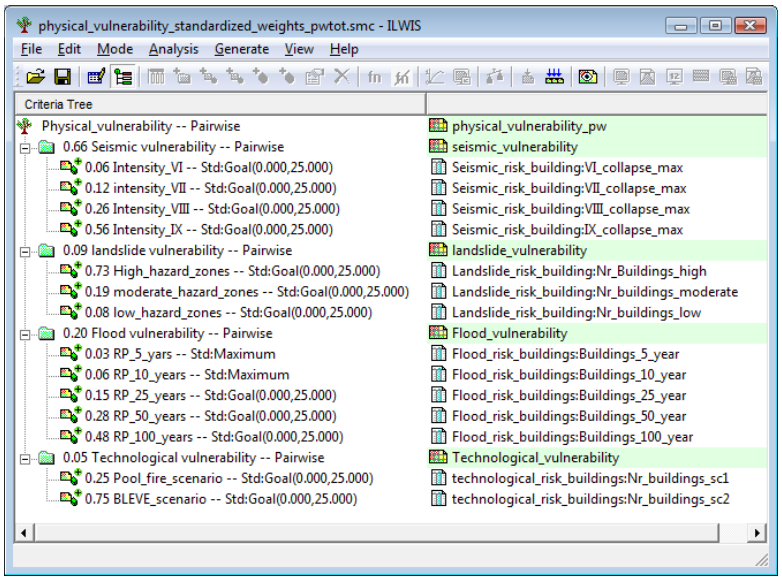


Figure 16 Standardized and weighted criterion tree for physical vulnerability

7.4 Vulnerability mapping

Once all the indicators are standardized and weighted you can calculate the output map, in this case the physical vulnerability map.

☞

- Right-click the map icon "**Physical_vulnerability**", and select Generate selected item.
- Display the result map.
- Use *PixelInfo* to compare the overall vulnerability map with the four sub-goal maps.
- You can adjust the standardization and/or weights if you would like to make adjustments. Save those adjustments under a different criterion tree name and also give different names to the output maps (if you want to keep the original ones).

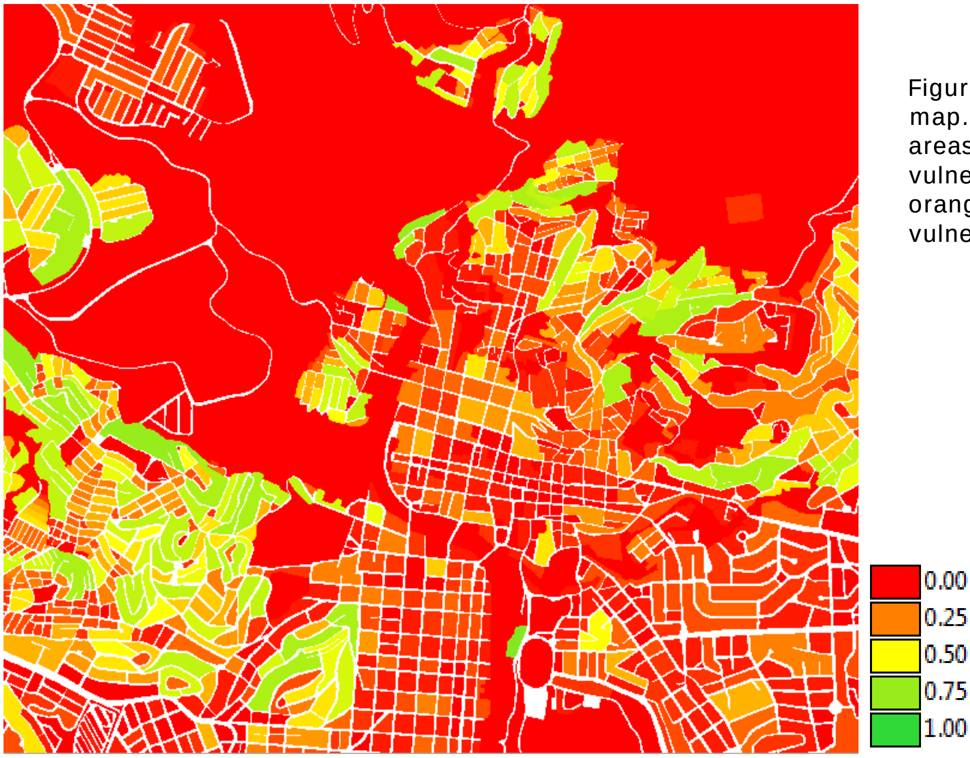


Figure 17 Physical vulnerability map. The green colours represent areas (pixels!) with a high vulnerability and the red and orange colours areas with a low vulnerability.

QUESTIONS

- What can you conclude from the pattern of physical vulnerability?
- Which indicators contribute most to the overall social vulnerability?

8. Capacity indicators

The overall vulnerability goal also contains a sub-goal related to capacity. Capacity expresses the positive managerial and operational resources and procedures for reducing risk factors. These actually help to reduce the vulnerability. In our case study we are using two capacity criteria: distance to emergency centres and awareness level, expressed by the literacy rate.

Be aware that the capacity indicators are different from the other vulnerability indicators. Where in case of the vulnerability indicators higher values are indicating a higher vulnerability, we want the capacity indicator to show us that the higher the value the better is the capacity.
The input data needed for this assessment come from two different administrative units. The three indicator maps for the distance to emergency centres are attribute data of the map 'Mapping_units' and the indicator map for awareness level is linked to the Ward map.

☞

- Create a new criteria tree: **Capacity**, and give the file and output map name also the same name.
- Add the groups: **Distance_emergency_centres** and **Disaster_Awareness.**
- Under the group Distance_emergency_centres, include three factors: **distance_hospitals, distance_policestation** and **distance_firestation**.

- Under the group Disaster_Awareness, include one factor: **Literacy_rate**. Select the column **Literacy_rate** from the table **Wards**.
- Standardize the factors, keeping in mind that high values of the three factors within the group distance_emergency_centres result in low values of the capacity index, while high values of literacy rate result in high values of the capacity index.
- Generate the output map Capacity, and critically evaluate the result.

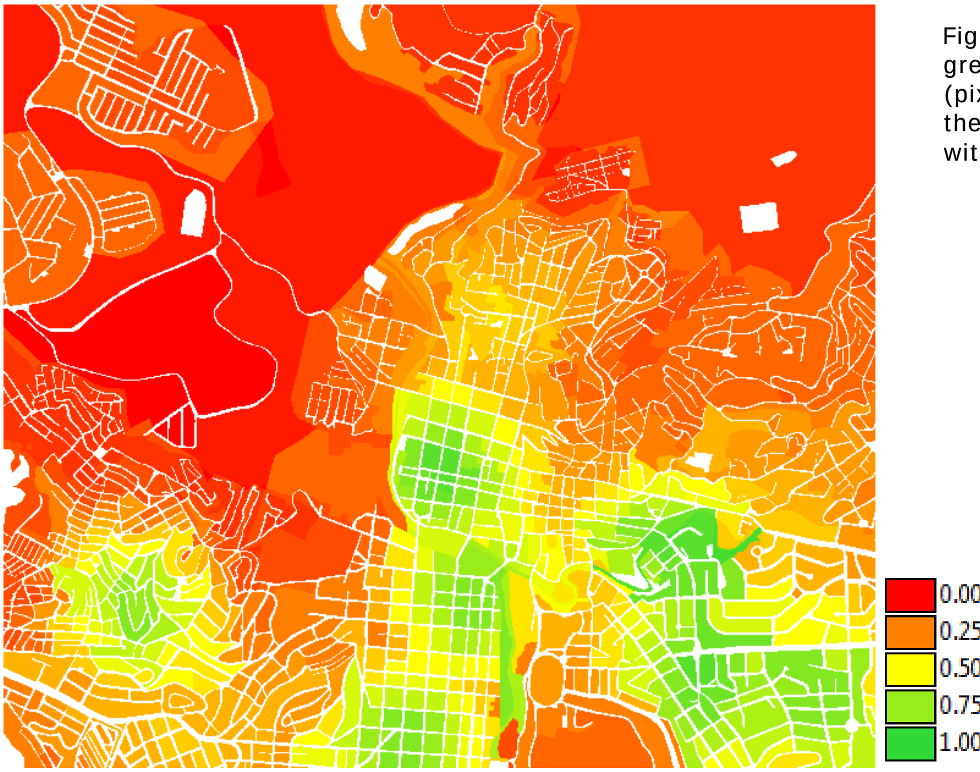


Figure 17 Capacity map. The green colours represent areas (pixels!) with a high capacity and the red and orange colours areas with a low capacity.

QUESTIONS

- What can you conclude from the pattern of capacity vulnerability?
- Which indicators contribute most to the overall capacity?

9. Combing vulnerability and capacity indicators

The overall vulnerability indicator is made by combining the four indicators that we have calculated thus far:

- Social_Vulnerability (Part 5)
- Population_Vulnerability (Part 6)
- Physical_Vulnerability (Part 7)
- Capacity (Part 8)

It is possible to combine all 4 results together in SMCE and create different scenarios based on different stakeholder perceptions (visions). Some stakeholders may, for example, find the social indicators more important while others may give more weight to the physical or capacity indicators. In a group decision making workshop we will create different scenarios, e.g. a Social vision, a Physical vision and a Capacity vision.

☞

- Create a new criteria tree: **Total_vulnerability_social** and give the same names to the output file and map.
- Add four spatial factors: **Social_vulnerability, Population_vulnerability**, **Physical_vulnerability** and **Capacity_indicators**.
- Link them to the four maps that were made in Part 5 , 6, 7 and 8.
- Standardize the four factors, and use the pairwise method for the determination of the weights, according to the 'social vision' scenario.
- Generate the output map **Total_vulnerability_social**.
- Classify the output map in five classes and critically evaluate the result. (Create an histogram from the **Overall_vulnerability** and select 5 classes).
- Repeat the same for the other two possible scenarios (physical and capacity)

QUESTIONS

- Which indicator(s) represent(s) a cost function?

For each scenario:

- Which areas have the highest vulnerability?
- Which indicator(s) contribute(s) most to the highest overall vulnerability?

Compare the three scenario maps:

- Determine which areas have the highest vulnerability in all the three scenarios?

Annex 1 Overview of available data for Social vulnerability assessment

Map	Table	Column	Meaning
Districts	Districts	Age_under_4	Percentage of young children, of pre-school age
	Districts	Age_4_to_12	Percentage of children, of primary school age
	Districts	Age_12_18	Percentage of teenagers, of secondary school age
	Districts	Age_18_24	Percentage of adolescents, following further education
	Districts	Age_24_65	Percentage of population in working age
	Districts	Age_over_65	Percentage of retired people.
	Districts	Minor	Percentage of population coming from minority groups.
	Wards	Unemployment	Unemployment rate per ward
	Mapping units	Percent_single_ household	Percentage single household per mapping units
	Mapping units	Poverty_level	Percentage of population in mapping unit living below poverty level
	Mapping units	Age_under_4	Percentage of young children, of pre-school age
	Mapping units	Age_4_to_12	Percentage of children, of primary school age
	Mapping units	Age_12_18	Percentage of teenagers, of secondary school age
	Mapping units	Age_18_24	Percentage of adolescents, following further education
	Mapping units	Age_24_65	Percentage of population in working age
	Mapping units	Age_over_65	Percentage of retired people.
	Mapping units	Unemployment	Unemployment rate per ward
	Mapping units	Minor	Percentage of population coming from minority groups.

Annex 2 Overview of available data for population vulnerability

Map	Table	Column	Meaning
Table: Mapping units Indicator: Flood risk to people	Flood_risk_population	day_pop_aff_10_year day_pop_aff_50_year	Number of people affected by a flood with a return period of 10 ans 50 years, during daytime
	Flood_risk_population	night_pop_aff_10_year night_pop_aff_50_year	Number of people affected by a flood with a return period of 10 ans 50 years, during nighttime
Table: Mapping units Indicator: Landslide risk to people	Landslide_risk_population	Pop_night_high Pop_night_moderate Pop_night_low	Number of people living in the high, moderate and low landslide susceptible zones during the nighttime
	Landslide_risk_population	Pop_day_high Pop_day_moderate Pop_day_low	Number of people living in the high, moderate and low landslide susceptible zones during the daytime
Mapping units Indicator: Technological risk to people	Technological_risk_population	Pop_day_sc1	Number of people being present in the area that might be affected by pool fire during the day
	Technological_risk_population	Pop_night_sc1	Number of people being present in the area that might be affected by pool fire during the night
	Technological_risk_population	Pop_day_sc2	Number of people being present in the area that might be affected by BLEVE (explosion) during the day
	Technological_risk_population	Pop_night_sc2	Number of people being present in the area that might be affected by BLEVE (explosion) during the night
Mapping units Indicator: Seismic risk to people	Seismic_risk_population	VI_night_pop VII_night_pop VIII_night_pop IX_night_pop	Population in buildings of buildings that collapse under VI – IX earthquakes in the night
	Seismic_risk_population	VI_day_pop VII_day_pop VIII_day_pop IX_day_pop	Population in buildings of buildings that collapse under VI – IX earthquakes in the night

Annex 3 Overview of available data for physical vulnerability

Map	Table	Column	Meaning
Mapping units	Flood_risk_buildings	Buildings_5_year	Number of buildings affected by a flood with a return period of 5 years
	Flood_risk_buildings	Buildings_10_year	Number of buildings affected by a flood with a return period of 10 years
	Flood_risk_buildings	Buildings_25_year	Number of buildings affected by a flood with a return period of 25 years
	Flood_risk_buildings	Buildings_50_year	Number of buildings affected by a flood with a return period of 50 years
	Flood_risk_buildings	Buildings_100_year	Number of buildings affected by a flood with a return period of 100 years
Mapping units	Landslide_risk_buildings	Nr_buildings_high	Number of buildings located in the high susceptible zones for landslides
	Landslide_risk_buildings	Nr_buildings_moderate	Number of buildings located in the moderate susceptible zones for landslides
	Landslide_risk_buildings	Nr_buildings_low	Number of buildings located in the low susceptible zones for landslides
Mapping units	Technological_risk_buildings	Nr_buildings_sc1	Number of buildings located in the area that might be affected by pool fire
	Technological_risk_buildings	Nr_buildings_sc2	Number of buildings located in the area that might be affected by BLEVE
Mapping units	Seismic_risk_buildings	VI_collapse_max	Number of buildings that are expected to collapse under a VI intensity earthquake
	Seismic_risk_buildings	VII_collapse_max	Number of buildings that are expected to collapse under a VII intensity earthquake
	Seismic_risk_buildings	VIII collapse_max	Number of buildings that are expected to collapse under a VIII intensity earthquake
	Seismic_risk_buildings	IX_collapse_max	Number of buildings that are expected to collapse under a IX intensity earthquake

Annex 4 Overview of available data for Capacity

Map	Table	Column	Meaning
Mapping units	Mapping units	Distance_hospital	Distance to hospitals
	Mapping units	Distance_MU_police	Distance to police stations
	Mapping units	Distance_MU_fire	Distance to fire stations
Wards	Wards	Literacy_rate	Literacy rate per ward