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# **IncREO**

## **Increasing Resilience through Earth Observation**

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### ***Deliverable 303-4&5: Delivery note of the RiskChanges Spatial Decision support system***

Work Package 303 Partners:  
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## ACRONYMS

EC	European Commission
REA	Research Executive Agency
AoI	Area of interest
SDSS	Spatial decision support system
CBA	Cost & Benefit analysis
IRR	Internal Rate of return
NPV	Net Present Value
BCR	Benefit-Cost Ratio
RRA	Risk Reduction Alternative
RM	Risk Module
SEI	Software Engineering Institute
AU	Administrative Unit
AUM	Administrative Unit Map
EUO	European Union Organization
EAR	Element at Risk
MCDM	Multi-Criteria Decision Making
AU	Administrative Unit
AUM	Administrative Unit Map
EUO	European Union Organization
AAL	Average annualized losses

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## **1. Executive Summary**

Within the framework of the EU FP7 Marie Curie Project CHANGES ([www.changes-itn.eu](http://www.changes-itn.eu)) and the EU FP7 Copernicus project INCReO (<http://www.increo-fp7.eu>) a spatial decision support system was developed with the aim to analyse the effect of risk reduction planning alternatives on reducing the risk now and in the future, and support decision makers in selecting the best alternatives. The Spatial Decision Support System is composed of a number of integrated modules. The Risk Assessment module allows to carry out spatial risk analysis, with different degrees of complexity, ranging from simple exposure (overlay of hazard and assets maps) to quantitative analysis (using different hazard types, temporal scenarios and vulnerability curves) resulting into risk curves. The system does not include a module to calculate hazard maps, and existing hazard maps are used as input data for the risk module. The second module of the SDSS is a data input and management module. This module includes the definition of risk reduction alternatives (related to disaster response planning, risk reduction measures and spatial planning) and links back to the risk assessment module to calculate the new level of risk if the measure is implemented. The third module is a cost-benefit module to compare the alternatives and make decision on the optimal one. The fourth module of the SDSS is a multi-criteria evaluation module that uses the risk data and cost-benefit data in combination with user defined criteria in order to make the selection of the optimal risk reduction measure.. The fifth module is a communication and visualization module, which can compare scenarios and alternatives, not only in the form of maps, but also in other forms (risk curves, tables, graphs). The envisaged users of the system are organizations involved in planning of risk reduction measures, and that have staff capable of visualizing and analysing spatial data at a municipal scale.

The system is online, and can be accessed through the following URL:

<http://changes.itc.utwente.nl/RiskChanges/>

The documentation for the system can be accessed through the system itself, or directly from the following URL:

<http://www.changes-itn.eu/RiskChanges/tabid/158/Default.aspx>

There the user can find the User Guide for each of the components, and a tutorial on the use of the system.

## 2. Introduction

A Spatial Decision Support System (SDSS) is a *“Interactive computer systems designed to support a user or a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem”* (Sugumaran et al. 2007). An SDSS has an explicit geographic component; it is supporting rather than replacing the user’s decision making skills, and facilitates the use of data, models and structured decision processes in decision making. A spatial decision support system has been developed with the aim to analyse the effect of risk reduction planning alternatives on reducing the risk now and in the future, and support decision makers in selecting the best alternatives.

The SDSS is able to analyse the effect of risk reduction planning alternatives on reducing the risk now and in the future, and support decision makers in selecting the best alternatives. Error: Reference source not found shows a concept of the SDSS.

Central to the SDSS are the stakeholders. The envisaged users of the system are organizations involved in planning of risk reduction measures, and that have staff capable of visualizing and analyzing spatial data at a municipal scale. The SDSS should be able to function in different countries with different legal frameworks and with organizations with different mandates. These could be subdivided into:

- Civil protection organization with the mandate to design disaster response plans.
- Expert organizations with the mandate to design structural risk reduction measures (e.g. dams, dikes, check-dams etc).
- Planning organizations with the mandate to make land development plans.

Another set of users are those working in organizations that are responsible for providing hazard maps related to flooding and landslides. These are different from the end –users, and they should provide relevant information on request of the end-users. These users are information –providers and are not using the system to make new hazard maps.

A third set of users are those that provide data on elements-at-risk. They are related to organizations related to cadastral data, transportation organizations, etc.

Risk modeling is the central module of the SDSS. It could be carried out by the main stakeholders or by special organizations that deal with risk assessments. In the SDSS design both options are possible.

The SDSS can be used in different ways (See figure 1):

- A. Analyzing the current level of risk.** In this workflow the stakeholders are interested to know the current level of risk in their municipality. They request expert organizations to provide them with hazard maps, asset maps, and vulnerability information, and use this information in risk modeling. They use the results in order to carry out a risk evaluation.
- B. Analyzing the best alternatives for risk reduction.** In this workflow the stakeholders want to analyze the best risk reduction alternative, or combination of alternatives. They define the alternatives, and request the expert organizations to provide them with updated hazard maps, assets information and vulnerability information reflecting the consequences of these scenarios. Note that we do not envisage in the SDSS that these maps are made inside of the system, as they require specialized software and expert knowledge. Once these hazard and asset maps are available for the scenarios, the new risk level is analyzed, and compared with the existing risk level to estimate the level of risk reduction. This is then evaluated against the costs (both in terms of finances as well as in terms of other constraints) and the best risk reduction scenario is selected. The planning of risk reduction measures (alternatives) involves:
  - **Disaster response planning:** focusing on analyzing the effect of certain hazard scenarios in terms of number of people, buildings and infrastructure affected. It can also be used as a basis for the design of early warning systems.

- **Planning of risk reduction measures**, which can be engineering measures (such as dikes, check-dams, sediment catchment basins), but also non-structural measures such as relocation planning, strengthening/protection of existing buildings etc.
  - **Spatial planning**, focusing on where and what types of activities are planned and preventing that future development areas are exposed to natural hazards.
- C. **The evaluation of the consequences of scenarios to the risk levels.** The scenarios are related to possible changes related to climate, land use change or population change due to global and regional changes, and which are not under the control of the local planning organizations. The systems will be evaluated how these trends have an effect on the hazard and assets (again here the updated maps should be provided by expert organizations) and how these would translate into different risk levels.
- D. **The evaluation how different risk reduction alternatives will lead to risk reduction under different future scenarios** (trends of climate change, land use change and population change). This is the most complicated workflow in the SDSS, as it requires to calculate the present risk level, the effect of different risk reduction alternatives, and the overprinting of these on the scenarios. For each of these combinations of alternatives & scenarios new hazard, assets and risk maps need to be made.

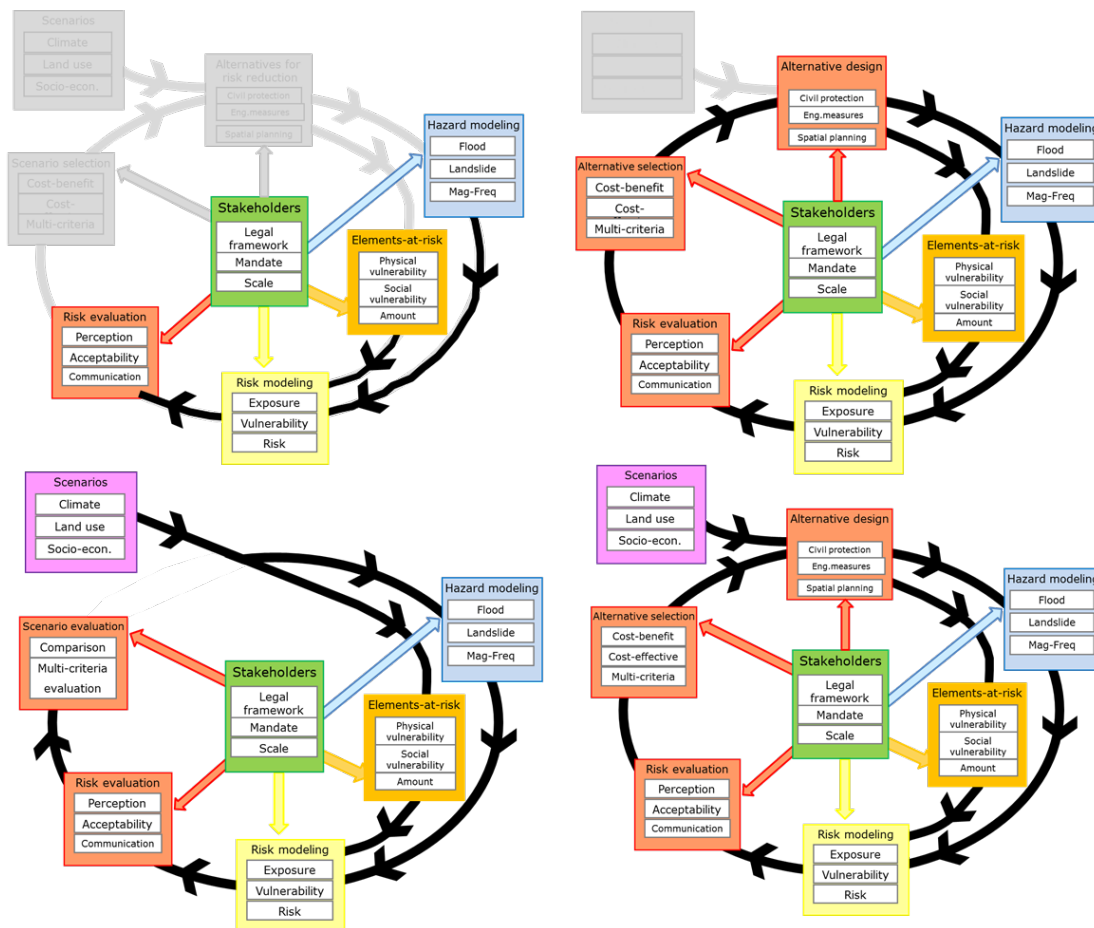


Figure 1: Different uses of the RiskChanges SDSS. Different colours refer to different components: **green** = stakeholders, **Blue** = organizations responsible for providing hazard maps. **Orange** = organizations responsible for providing elements at risk maps, **Yellow** = organizations responsible for providing risk modeling, **Violet** = Organizations that are working on the analysis of trends related to climate changes, land use change and population change, **Red** = end-users of the platform that use the information from the other. Upper left: analysing the current level of risk. Upper right: analysing different risk reduction measures. Lower left: analysing the effect of future scenarios on the risk. Lower right: analysing the behaviour of risk reduction measures under future scenarios.



### 3. System architecture

The SDSS is developed based on open source software and following open standards, for code as well as for data formats and service interfaces. Code development was based upon open source software as well. The architecture of the system is modular. The various parts of the system are loosely coupled, extensible, using standards for interoperability, flexible and web-based. Figure 2 gives an overview of the system architecture. A layered web application was designed using Model-View-Controller (MVC) pattern in combination with GeoServer and Geospatial databases for the Web GIS components of the system. The following tools were used in the design:

- Apache web server
- Tomcat application server
- PostGIS Spatial database (based on Postgres)
- Geoserver
- Netbeans for development environment
- PGAdmin III
- Python 2.7/3.3
- ExtJS 4.1 MVC Javascript library
- GeoExt Javascript library
- OpenLayers Javascript library

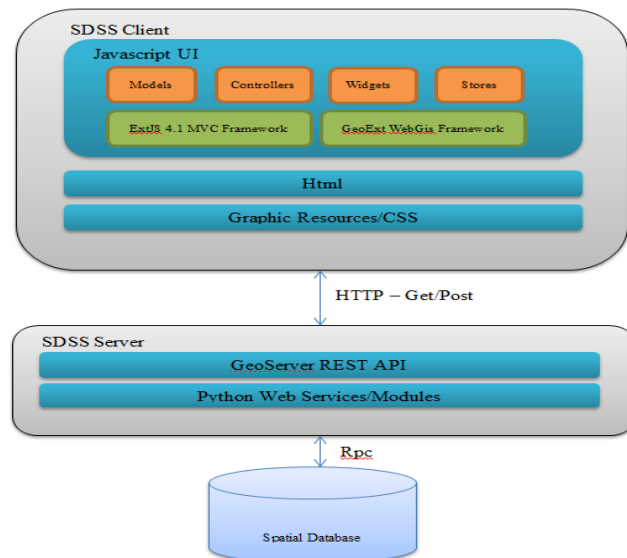
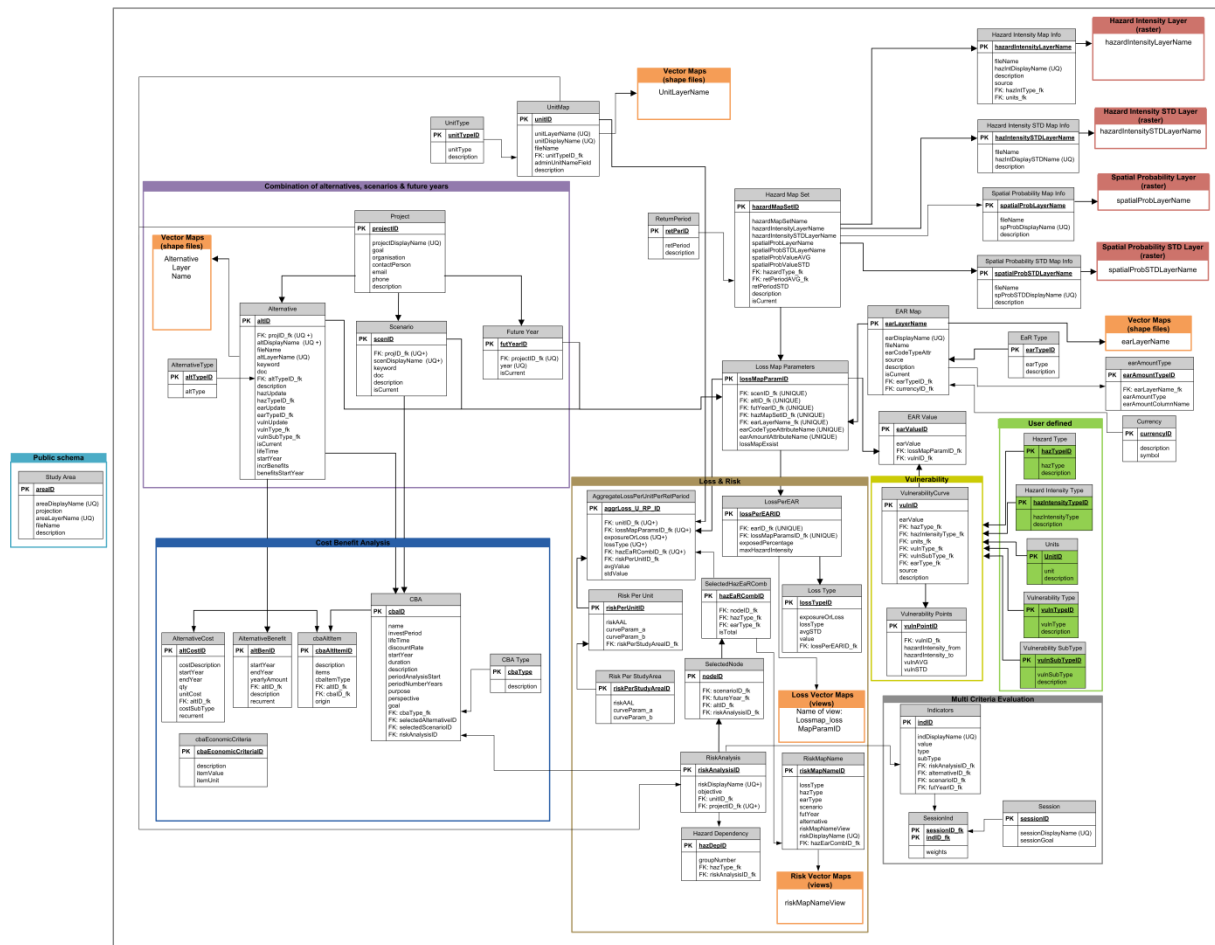


Figure 2: The system architecture

#### 3.1 Data Model

Figure 3 provides an overview of the data model of the SDSS. The highest level is formed by the definition of the study areas, as all other objects are linked to that. Users can generate their own study area. A study area may contain information on the current situation in terms of elements-at-risk and hazards. Although the system is designed originally for hydro-meteorological hazards, like flooding and landslides, it can also be used for other hazard types, as long as hazards can be defined on the basis of intensity maps and/or spatial probability maps for different return periods. The hazards are treated as so called hazard map sets, which determine the type of hazard, the return period, the intensity of the hazard (measurement scale, average and/or standard deviation) and the spatial probability of the hazard. This approach allows the use of hazard data for which no intensity information is available (e.g. landslide susceptibility maps) but for which the probability of the event was estimated for the different classes of the map. Hazard maps are always in the form of raster maps (GeoTiff files) having a common projection. The system doesn't allow the use of maps with different projection in the same study area.

Element-at-risk data can be in four types: building footprint maps, land parcel maps, linear features (e.g. road networks) or point features (individual objects). When using two elements-at-risk maps together care should be taken that the information in the two layers is not duplicated (e.g. information on building also used in land parcel maps). Elements-at-risk maps should be in the form of vector data (shapefiles), with an attribute table containing information on the land use type, the structural type, the value and or the number of people. Several attributes columns for values (e.g. IncREO\_Del303.4 and 5 Delivery note of the RiskChanges SDSS

Schema  
(areaDisplayName)

*Benefit data.*

Included in the model is the management of a combination of different scenarios (e.g. global changes scenarios or population change scenarios) and alternatives (possible risk-reduction measures), as

6

well as data-structures for saving the calculated economic or population loss or exposure per element at risk, aggregation of the loss and exposure using the administrative unit maps, and finally, producing the risk.

## 4. System components

The SDSS is composed of the following integrated modules:

- **Data input module.** This module allows the users to create their own study area, upload maps representing the current situation of hazard maps and elements-at-risk. The users can create projects that deal with the generation of possible risk reduction planning alternatives and/or future scenarios in terms of climate change, land use change and population change, and the time periods for which these scenarios will be made. The module defines the input maps for the effect of the specific combinations of alternatives, scenarios and future years in terms of the hazard and assets maps. It also allows users to make the link between the elements-at-risk types and the vulnerability curves that are stored in a vulnerability database. Users can also enter or upload their own vulnerability curves.
- **Risk modeling module.** This module allows to carry out spatial risk analysis, with different degrees of complexity, ranging from simple exposure (overlay of hazard and assets maps) to quantitative analysis (using different hazard types, temporal scenarios and vulnerability curves) resulting into risk curves. The module first calculates the losses for specific combinations of hazards (in terms of hazard type and return period) and elements-at-risk. Users can then decide the type of risk assessment they would like to carry out (e.g. for specific hazard, specific elements-at-risk, economic risk or population risk and for which alternatives and scenarios). The system does not include a module to calculate hazard maps, as there are many different methods which are applied depending on the scale, available data and objectives of the study. Therefore, hazard maps are considered as input data for the risk module.
- **Cost-benefit analysis module.** This module uses the risk reduction alternatives defined under a project in the data input module and the risk results for the current situation and after implementing these alternatives. The risk is calculated in the risk assessment module. The user can define the costs for the alternatives, and carry out cost-benefit analysis for the alternatives, which also takes into account how the costs and benefits might change in future years depending on the possible future scenarios.
- **Multi-Criteria Decision module.** This module supports the users in determining the most optimal risk reduction alternative, based on the results of the risk assessment and the cost-benefit analysis, and on user defined criteria. These indicators are standardized, weighted and the optimal alternative under different possible future scenarios is determined.
- **Communication and visualization module.** Visualization is a very important module within the SDSS. The SDSS can use many scenarios and alternatives, and the organization of the data should be very well designed. The visualization is not only in the form of maps, but also in other forms (risk curves, tables, graphs). Also the methods for visualizing changes of maps through time should be well designed.

### 4.1 Accessing the system

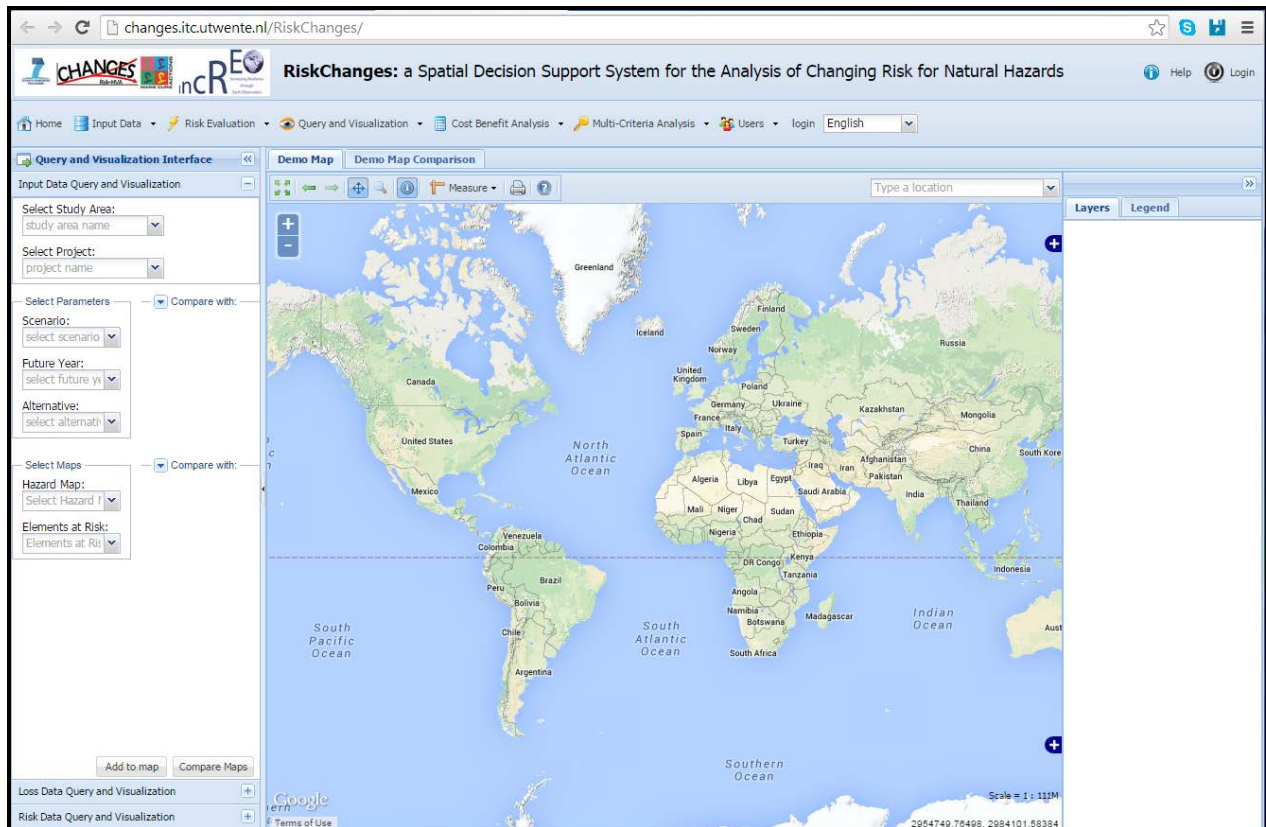
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<http://www.changes-itn.eu/RiskChanges/tabid/158/Default.aspx>

There the user can find the User Guide for each of the components, and a tutorial on the use of the system. The start page of the system is shown in Figure 4.



## **RiskChanges: a Spatial Decision Support System for analysing changing hydro-meteorological risk**

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**Goto  
RiskChanges**

**User Guide**

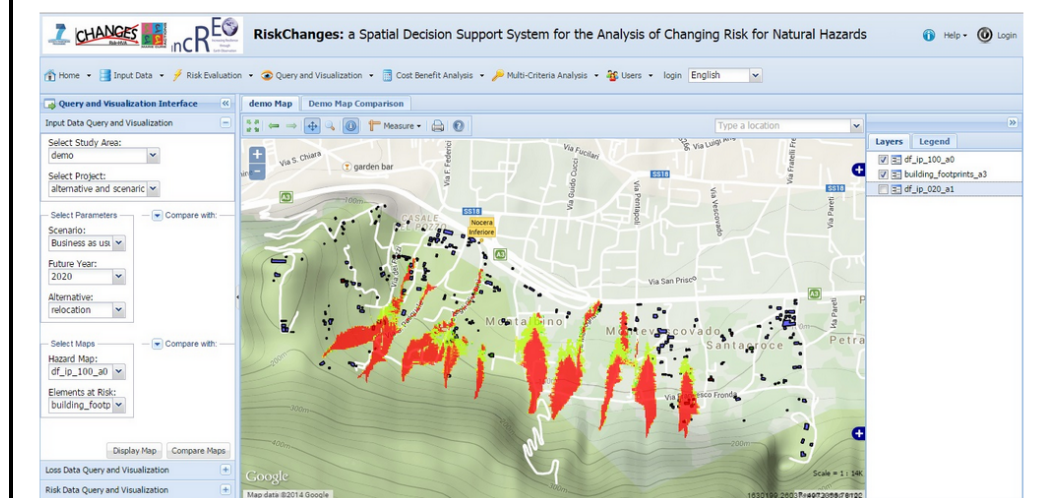
**Documentation**

**Tutorials**

**Source Code**

Within the framework of the EU FP7 Marie Curie Project **CHANGES** and the EU FP7 Copernicus project **INCOREO** a spatial decision support system was developed with the aim to analyse the effect of risk reduction planning alternatives on reducing the risk now and in the future, and support decision makers in selecting the best alternatives. The Spatial Decision Support System is composed of a number of integrated components. The Risk Assessment component allows to carry out spatial risk analysis, with different degrees of complexity, ranging from simple exposure (overlay of hazard and assets maps) to quantitative analysis (using different hazard types, temporal scenarios and vulnerability curves) resulting into risk curves. The platform does not include a component to calculate hazard maps, and existing hazard maps are used as input data for the risk component. The second component of the SDSS is a risk reduction planning component, which forms the core of the platform. This component includes the definition of risk reduction alternatives (related to disaster response planning, risk reduction measures and spatial planning) and links back to the risk assessment module to calculate the new level of risk if the measure is implemented, and a cost-benefit (or cost-effectiveness/ Spatial Multi Criteria Evaluation) component to compare the alternatives and make decision on the optimal one. The third component of the SDSS is a temporal scenario component, which allows to define future scenarios in terms of climate change, land use change and population change, and the time periods for which these scenarios will be made. The component doesn't generate these scenarios but uses input maps for the effect of the scenarios on the hazard and assets maps. The last component is a communication and visualization component, which can compare scenarios and alternatives, not only in the form of maps, but also in other forms (risk curves, tables, graphs)

**Go to the RiskChanges SDSS**



*Figure 4: Above: Opening screen of the RiskChanges SDSS. Below: Site for the documentation of the system.*

The following sections will give an overview of the different modules.

## 4.2 Data input module

The data input module deal with defining the study area, and the hazard and elements-at-risk data (see Figure5)

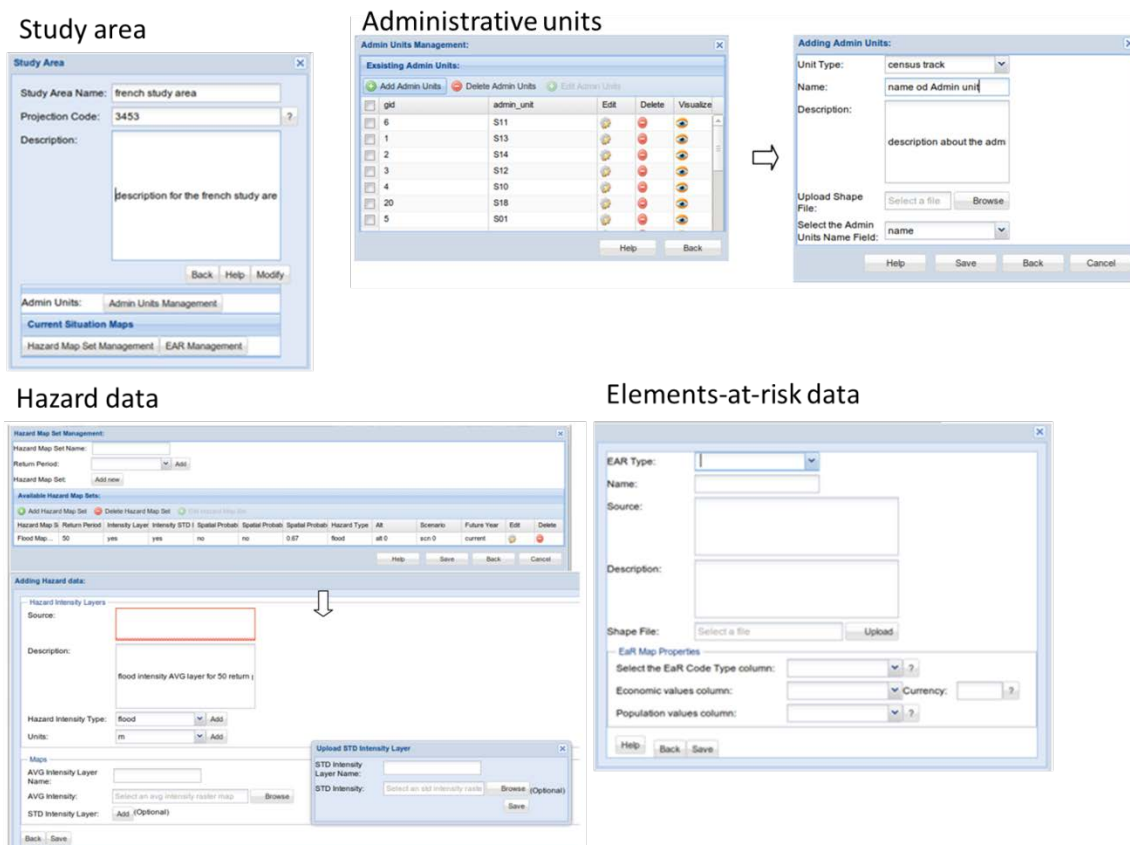


Figure 5: User interface for the data input of a study area, with hazard data and elements-at-risk data

Figure 6 shows the user interface for defining a project, which can have one or more risk reduction alternatives and one/or more possible future scenarios. In this figure an example is given of the demo project which has 3 risk reduction solutions (engineering solutions, ecological solutions and relocation) and 4 possible scenarios (business as usual, risk informed planning, worst case, and most realistic scenario) and the future years for which the user would like to see the risk changes (in this example 2020, 2030, and 2040).



## Project

**Add Project**

Project Name: First Nicosia Project

Goal: Mitigation of...

Description: Project description...

Organisation: Organisation Name...

Contact Person: Contact of the organisation

Email: Email of the responsible person

Phone: +43 654 123 456

Link to Alternatives and Scenarios

Alternative Definition Scenario Definition

Link to specific Hazard and EaR Maps

Set Parameters

Back Help Cancel

## Possible future scenarios

**Scenario Management**

Future Years: 2020 Add

Available Scenarios

Scenario Name	Keyword	Description	Edit	Delete
1 Population ch...	population	description fo...		
2 Climate change	climate	description fo...		
3 Land use cha...	land use	description fo...		

Help Save Back Cancel

**Adding Scenario**

Name: Population change

Keyword: population

Description: description for population

Upload PDF File: Select a file Browse

Relation between Scenario and Alternative

Indicators

Help Save Back Cancel

Combination of alternatives and scenarios

## Risk reduction Alternatives

**Risk Reduction Alternative Management**

Study Area: demo

Project: current situation and alternative

Name	Description	Edit	Delete	Visualize
1 no alternative	None			
2 engineering solutions	None			
3 ecological solutions	None			
4 relocation	None			

New Cancel

Name: engineering solutions

Keyword: None

Description: None

Upload PDF File: Select a file Browse

Visual Shape: Select a file Browse

Alternative Type: Structural

Start Year: 2014

End Year: 2020

When hazard starts: 1

When hazard ends: 1

Allow incremental benefits during investment period: [ ]

Is current situation: [ ]

Additional benefits: [ ]

Incremental benefits: [ ]

Element at Risk: [ ]

Vulnerability: [ ]

Search alternative: [ ]

Save

**Risk Analysis Dashboard**

Alternative	2014	2020	2030	2040
Scenario: Business as usual				
relocation				
engineering solutions				
ecological solutions				
no alternative				
Scenario: Most realistic				
relocation				
no alternative				
ecological solutions				
engineering solutions				
no alternative				
Scenario: No scenario				
engineering solutions				
relocation				
ecological solutions				
no alternative				
Scenario: Risk informed planning				
ecological solutions				
engineering solutions				
no alternative				
relocation				
Scenario: Worst case				
engineering solutions				
ecological solutions				
no alternative				
relocation				

Compute Risk Visualize Cancel

Figure 6: User interface for the data input of a project, with alternatives and scenarios

The system has also a separate vulnerability database, where users can query for available vulnerability curves, and add new ones. Also a link is made between the types of elements-at-risk and the available vulnerability curves. Figure 7 shows the user interface for the management of vulnerability curves.

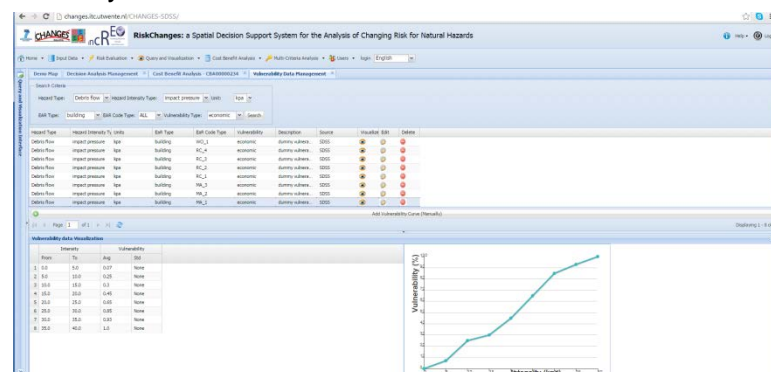


Figure 7: Vulnerability curve management within the system.

### 4.3 Loss and risk analysis module

The goal of the risk assessment module within the SDSS to assess the current risk, analyze the risk after implementations of risk reduction alternatives, and analyze the risk in different future years when considering scenarios such as climate change, land use change and population growth. Not only the single-hazard but also the multi-hazard risk assessment is included in this module. As intermediate products in computing risk, loss maps for individual combinations of hazard maps and elements-at-risk maps are generated. The risk assessment module is the central module within the system, and it is closely connected with all the other ones. The input data required by this module, including hazard maps combined with Elements-at-Risk (EaR) and vulnerability, are provided by external organizations or entered by the user through data input module. The outputs of risk assessment module are the basis for cost benefit and multiple criteria evaluation modules. Moreover, the loss and risk maps and curves can be visualized by the visualization module.

This module is developed using an Ext JS library for the implementation of the user interface on the client side, using Python for scripting, as well as PostGIS spatial functions for complex computations on the server side. The risk assessment module is subdivided into two modules: loss estimation and risk analysis. The loss estimation module produces a number of loss maps based on the combinations of hazard maps and elements-at-risk maps with vulnerability curves.

Four steps should be conducted to compute loss (See figure 8): first overlay of the hazard intensity layer and the spatial probability layer with the EaR layer, then compute the intensity and spatial probability for each EaR. Retrieve the vulnerability value for each EaR based on the hazard type, EaR class and the intensity value. Finally the loss is computed as the product of EaR economic value (or population number), vulnerability and spatial probability.

The risk analysis module calculates risk using the outputs of the loss estimation module. The risk can be simple (only exposure information if no return periods are available) or more quantitative. Risk analysis consists of 4 steps as well if the hazard data contains at least 2 return periods: aggregates loss values in administration units, simulate the risk curve which is exponential based, then calculate the annualized risk value, and finally the risk value and curve for the whole study area could be visualized.

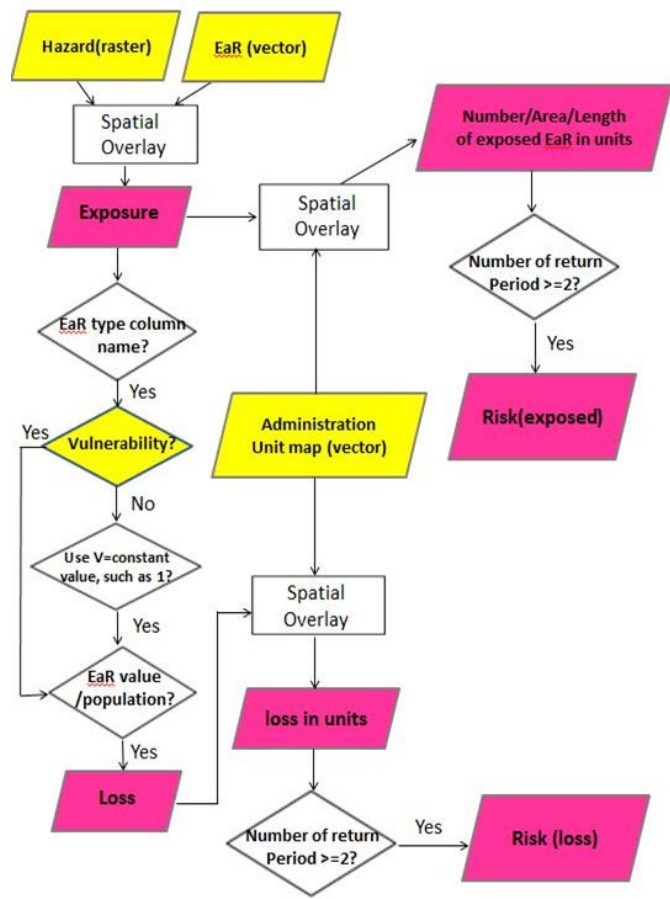


Figure 8: Flow chart of Risk assessment module. The box filled by yellow color indicates the input data, while the ones in red are outputs

The risk analysis dashboard (See Figure 6 Lower right) contains all the combinations of scenarios, alternative and future years under the selected study area and project. Each combination is shown as a checkbox in the user interface. The disabled checkbox indicates that no input data, or not enough return periods are available to conduct the risk analysis under this combination. When users tick an enabled checkbox, a pop-up window appears. The window contains all the combination of hazard type and EaR, as well as total options. If users tick the checkbox with 'hazard' type equaling to 'Total' and 'EaR' type 'Building', it means that the risk of building under all the hazard types (flood, landslide and debris flow in this case) will be computed. The dependency of the hazards is determined before it is used in this computation. Once users click the button 'Compute Risk' in the risk analysis dashboard user interface, all the corresponding risk curve parameters are simulated using least square method and risk values are computed based on the equation below.

$$\text{Risk} =$$

Where T1, T2 etc. are the return periods used, and S1, S2 etc. are the losses. Results are shown as risk curves and data on average annualized loss can be exported as Excel file.

## 4.4 Cost-Benefit analysis module

Cost benefit analysis (CBA) is a well know method for the assessment of investments either in the private and public sector. In the context of risk mitigation and the evaluation of risk reduction alternatives for natural hazards its use is very important to evaluate the effectiveness of such efforts in terms of avoided monetary losses. Decision-makers are often interested in how the costs and benefits are distributed among different administrative units of a large area or region, so they will be able to compare and analyze the costs and benefits. In the current implementation users can define the costs for the defined risk reduction alternatives (RRA) for a given project and also add additional benefits and costs in the analysis, also user has the option of choosing the proper AAL values from the risk module to get an overall estimation of the yearly benefits, and the problem of discounting these future values using a user defined interest rate is contemplated. Figure 9 gives an example of the user interface of the cost-benefit module. The cost-benefit analysis for alternatives in combination with possible future scenarios uses the calculated risk for future years, and will therefore also change the risk reduction for these years. For intermediate years the data is interpolated.

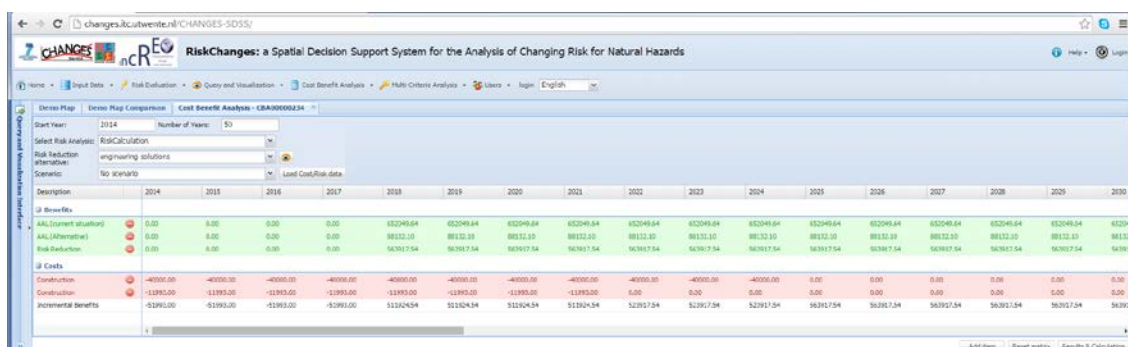


Figure 9: the structure of the cost-benefit analysis module, where users can indicate the costs and benefits for different risk reduction alternatives, in addition to the risk reduction calculated through the risk analysis module of the system.



This allows users to take future changes into account in a cost-benefit analysis, instead of keeping the risk reduction constant for the entire project lifetime, as would be the case when we would only look at the current situation.

## 4.5 Multi-Criteria Evaluation module

The aim is to use the risk information calculated in the risk assessment modules and the cost benefit indicators (BCR, NPV and IRR) that resulted from the cost-benefit analysis module, as input for each of the considered risk reduction alternatives in the Multi-criteria evaluation module. These are the combined with user-defined other indicators. The indicators are standardized, and weighted and the system will show the score for each of the risk reduction alternatives (See Figure 10).

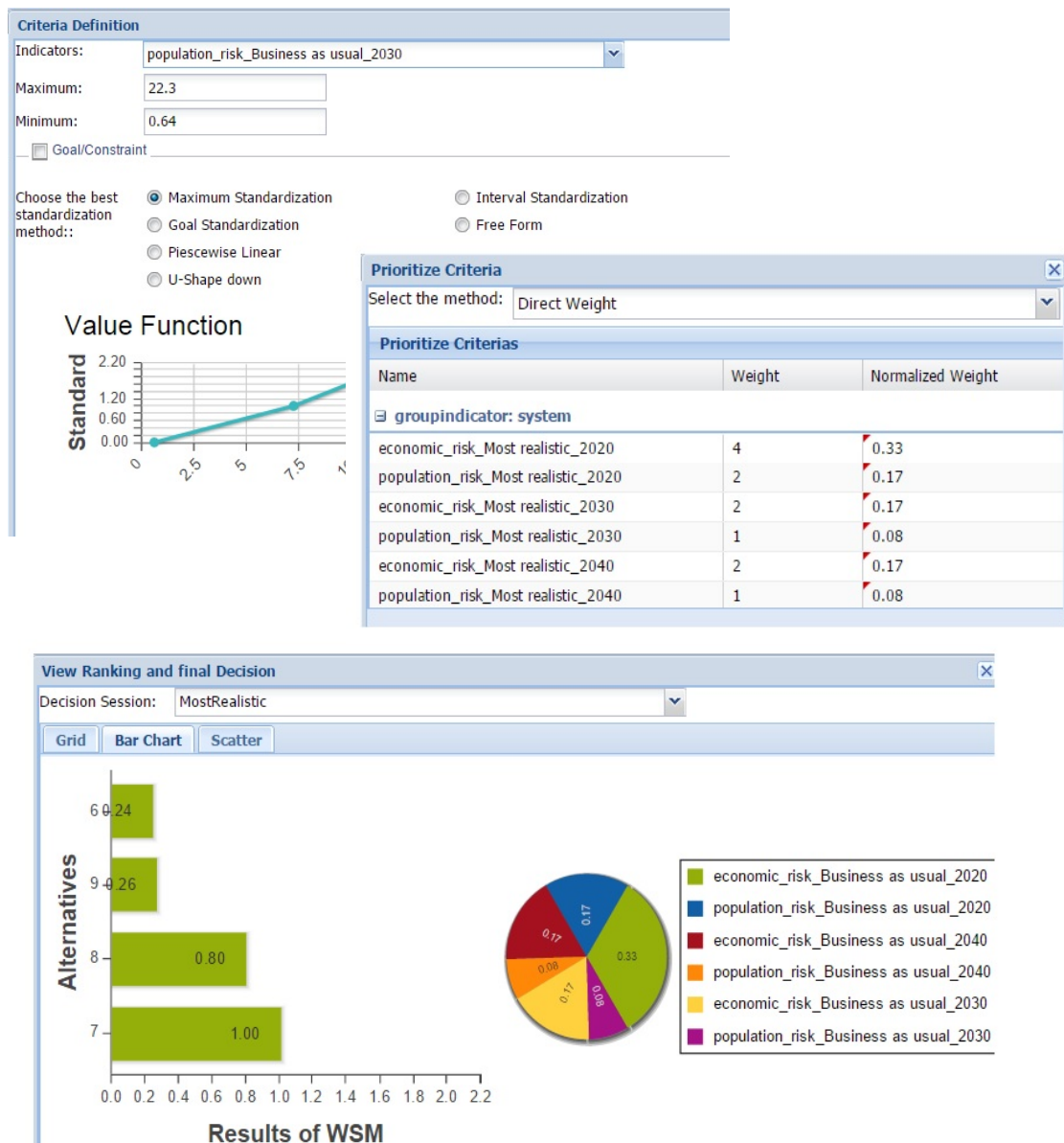


Figure 10: Standardization(criteria definition), prioritizing (weighting) criteria and ranking the alternatives: After analysing the risk after implementing the alternatives, the user can analyse the costs of the alternatives, and make a cost-benefit analysis, leading to a prioritization of the alternatives. In this specific example: The multi-criteria evaluation has been down under one scenario called most-realistic for different future years 2020, 2030 and 2040. In the results alternative 7 called as engineering solutions ranked as best risk reduction alternative.

## **4.6 Visualization module**

The complexity of the information related to the different modules of the RiskChanges SDSS requires explicit tools for the data retrieval and visualization. For the implementation of the visualization module, the GeoExt and ExtJS javascript libraries are used. Python scripting language is used on the server side to connect to the database.

The visualization module has been designed and implemented according to the particular needs of the end users. The usability of the tool has been verified, at the implementation stage, from the two main categories of the end-users, which are GIS experts (mostly urban planners) and non-GIS experts (decision makers).

A menu of three options is provided to the users: input data visualization, loss data visualization and risk data visualization (See Figure 11). Each of them has an interface for querying/filtering data by selecting study area, project, scenario, alternative and future year, hazard type etc. The parameters differ depending on the type of the data.

Precondition for using the query and visualization module is to perform the data uploading and the risk analysis, since the data has to be stored in the database before querying.

Python scripting language is used to connect and query the database, while the ExtJS scripts bind this information with the actual interface.

The visualization options are several, depending on the scope. The simplest is to visualize a single map from the specified data. The result is a web-GIS application with functionalities such as navigation, geo-location, distance measurement etc. The other option is to compare two maps by selecting a second dataset in the respective interface. The comparison interface displays two map panels and provides three comparison methods:

1. Swiping tool – permits layers' comparison
2. Linked views – permits maps' comparison side by side
3. Time animation – generates an animated image from the specified data.

## **5. Using the SDSS for selected case study developed in the WP205 programme**

### **5.1 Demo dataset**

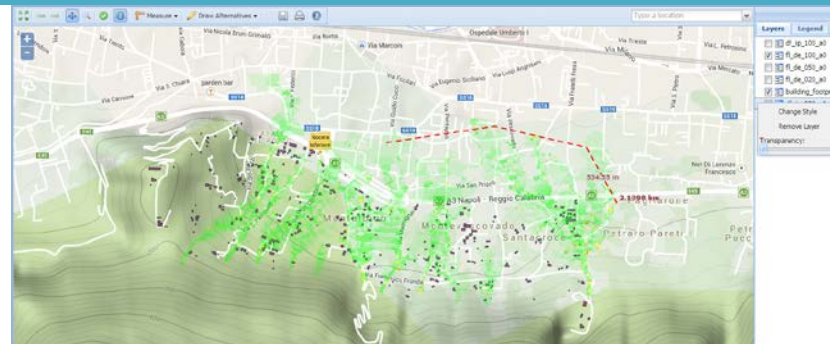
The RiskChanges SDSS has been developed from scratch, and was a very large effort. We have managed to develop the system based on a case study of a dataset from Italy. For this area we obtained all the required input data in order to be able to demonstrate the functionality of the system, which included hazard maps (See Figure 12), and elements-at-risk maps. We used the demo dataset to illustrate all possibilities of the system, and created three risk reduction alternatives (engineering solutions, ecological solutions and relocation, See Table 1) and four possible future scenarios (See table 2 and Figure 13)

With the use of the demo dataset all functionalities of the system can be illustrated. It is possible to carry out a loss and risk assessment for the current situation, for single hazards or multiple hazards in combination with single elements-at-risk or multiple elements-at-risk. Vulnerability curves are also used in the system. It is also possible to formulate different risk reduction alternatives and to determine the new risk situation after the implementation. The risk before and after implementation can be compared, and the risk reduction can be quantified. This can be used in the cost-benefit analysis and multi-criteria evaluation for the selection of the optimal alternative.

## Data Filtering

Input Data Filtering	Loss Data Filtering	Risk Data Filtering
<b>Input Data Query and Visualization</b>		
Study Area: <input type="text" value="demo"/>		
Project: <input type="text" value="current situation"/>		
Select Parameters		
<input type="text" value="select scenario"/>	<input type="text" value="No scenario"/>	
<input type="text" value="select future year"/>	<input type="text" value="2014"/>	
<input type="text" value="select alternative"/>	<input type="text" value="no alternative"/>	
Select Maps		
<input type="text" value="Select Hazard Map"/>	<input type="text" value="fi_de_020_a0, fi_de_050"/>	
<input type="text" value="Elements at Risk Map"/>	<input type="text" value="land_parcel, building_foo"/>	
<input type="text" value="land_parcel"/>		
<input type="text" value="building_footprints"/>		
<b>Loss Data Query and Visualization</b>		
Study Area: <input type="text" value="demo"/>		
Project: <input type="text" value="alternative and scenario"/>		
Select Parameters		
<input type="text" value="Business as usual"/>	<input type="text" value="select scenario"/>	
<input type="text" value="2030"/>	<input type="text" value="select future year"/>	
<input type="text" value="engineering solutions"/>	<input type="text" value="select alternative"/>	
Select Maps		
<input type="text" value="Debris flow"/>	<input type="text" value="Select Hazard Map"/>	
<input type="text" value="100"/>	<input type="text" value="Select Return Period"/>	
<input type="text" value="land_parcel_2030_a1_s1"/>	<input type="text" value="Elements at Risk Map"/>	
<input type="text" value="population"/>	<input type="text" value="Select Loss Type"/>	
<input type="text" value="Available Maps"/>	<input type="text" value="Available Maps"/>	
<input type="text" value="lossview_584"/>		
<b>Risk Data Query and Visualization</b>		
Study Area: <input type="text" value="demo"/>		
Project: <input type="text" value="current situation and al"/>		
Risk Analysis Name: <input type="text" value="RiskCalculation"/>		
Select Parameters		
<input type="text" value="No scenario"/>	<input type="text" value="scenario"/>	
<input type="text" value="2014"/>	<input type="text" value="future year"/>	
<input type="text" value="no alternative"/>	<input type="text" value="alternative"/>	
Select Maps		
<input type="text" value="Debris flow"/>	<input type="text" value="Select Hazard type"/>	
<input type="text" value="TotalColumn"/>	<input type="text" value="Elements at Risk Map"/>	
<input type="text" value="loss"/>	<input type="text" value="Select Exposure/Loss"/>	
<input type="text" value="economic"/>	<input type="text" value="Loss Type"/>	
<input type="text" value="Available Risk Maps"/>	<input type="text" value="Available Risk Maps"/>	

## Single Map Visualization

Web-GIS: Single Map Visualization	Functionalities
	<ul style="list-style-type: none"> <li>• Basic GIS tools (navigation, geo-location, measurement tool etc.)</li> <li>• Feature Info</li> <li>• Layer tree</li> <li>• Context Menu</li> <li>• Map Legend</li> </ul>

## Data Comparison

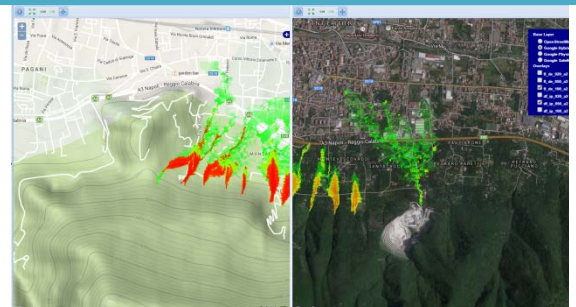
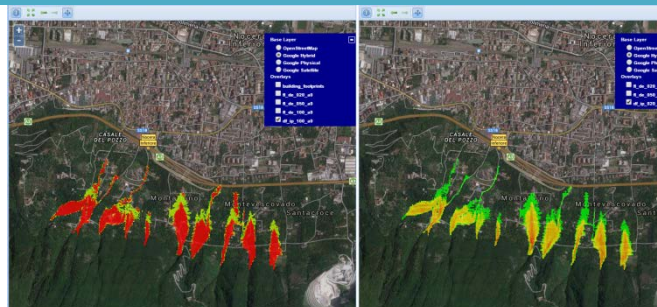
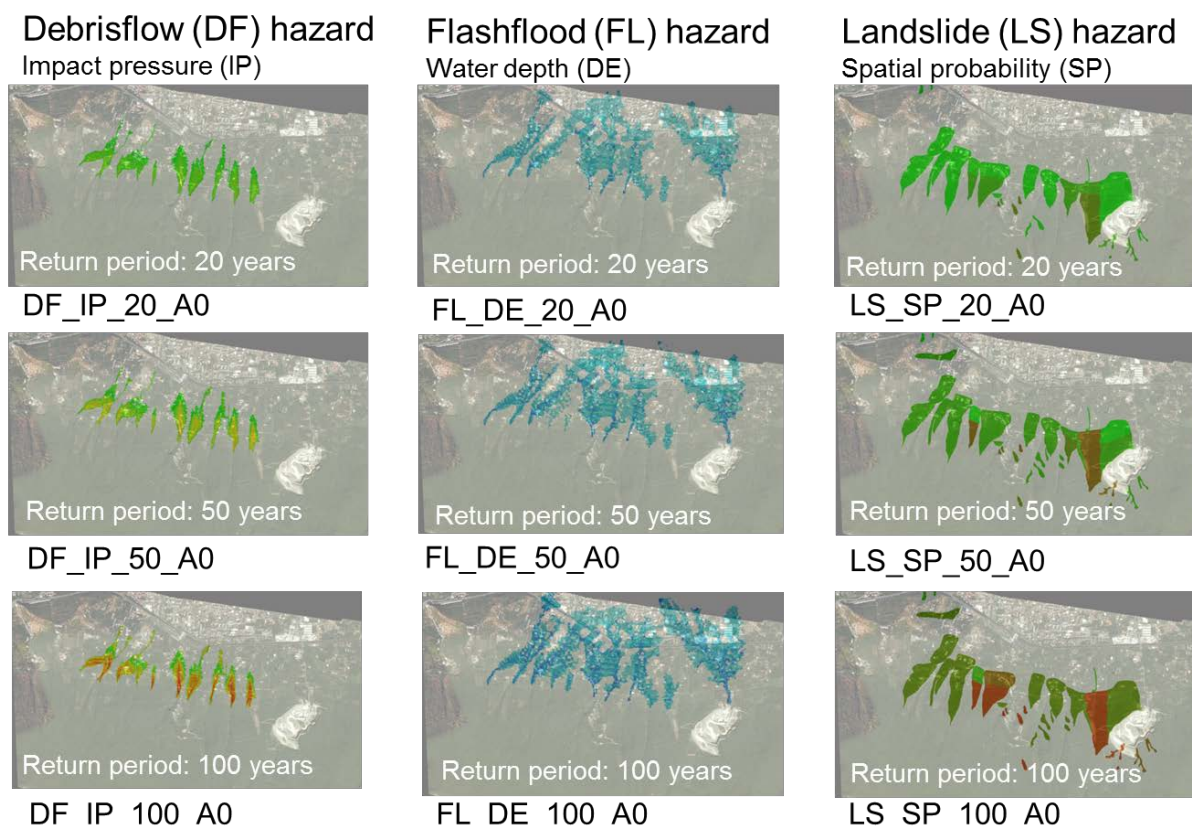
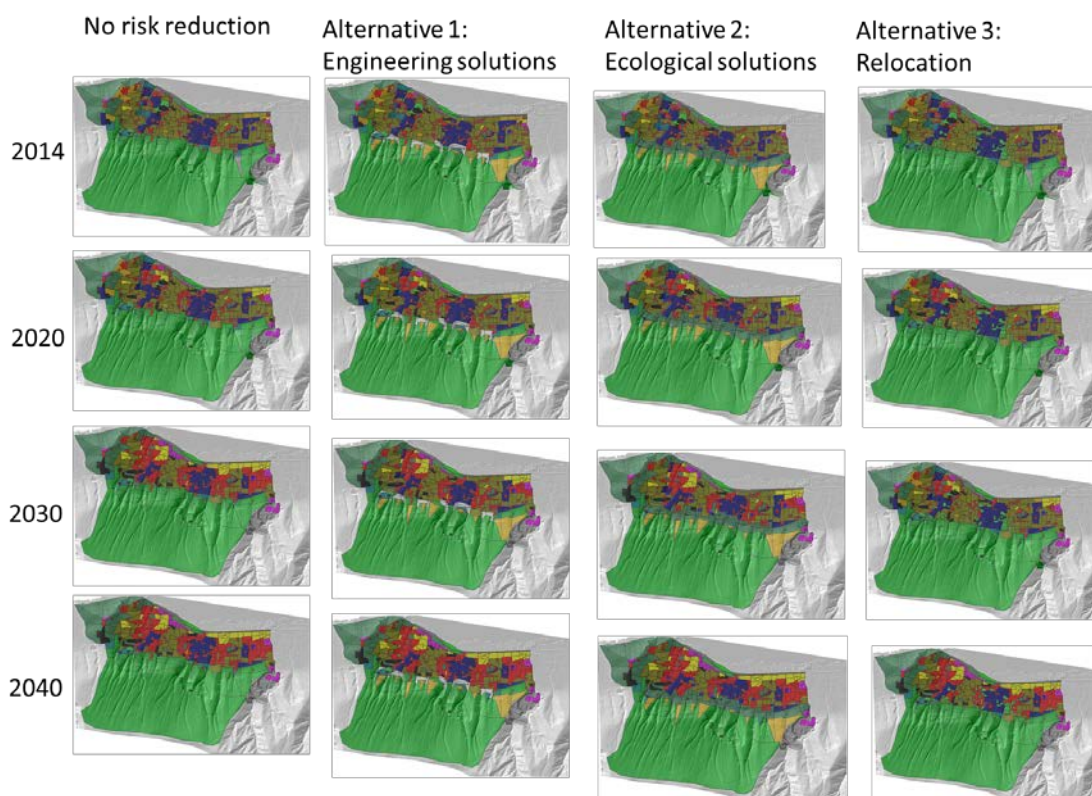
Swiping tool	Linked views
	

Figure 11: Different components of map visualization is the RiskCHANGES SDSS





*Figure 12: Application of the SDSS for a dataset from Italy, used a demonstration dataset. Here hazard data sets are shown for three types of hazards and three return periods*



*Figure 13: Application of the SDSS for a dataset from Italy, used a demonstration dataset. Here the land cover maps are shown for one scenario, covering different future years and different alternatives*

	Items related to construction cost	Hazard changes	Elements-at-risk changes
<b>Alternative 1: Engineering solutions</b>	<ul style="list-style-type: none"> <li>Storage basins</li> <li>Slope stabilization</li> <li>Expropriation of land and existing buildings where construction will take place</li> </ul>	Yes	No
<b>Alternative 2: Ecological solutions</b>	<ul style="list-style-type: none"> <li>Expropriation of land and existing buildings where construction will take place</li> <li>Slope stabilization</li> <li>Water tank construction</li> </ul>	Yes	Partly
<b>Alternative 3: relocation</b>	<ul style="list-style-type: none"> <li>Compensation of owners of buildings</li> <li>Expropriation of existing buildings</li> <li>Lawsuit</li> </ul>	No	Yes

*Table 1: Examples of alternatives used in the demo dataset.*

	Name	Land use change	Climate change
<b>Scenario 1</b>	Business as usual	Rapid growth without taking into account the risk information	No major change in climate expected
<b>Scenario 2</b>	Risk informed planning	Rapid growth that takes into account the risk information and extends the alternatives in the planning	No major change in climate expected
<b>Scenario 3</b>	Worst case	Rapid growth without taking into account the risk information	Climate change expected, leading to more frequent extreme events
<b>Scenario 4</b>	Most realistic	Rapid growth that takes into account the risk information and extends the alternatives in the planning	Climate change expected, leading to more frequent extreme events

*Table 2: Examples of alternatives used in the demo dataset.*

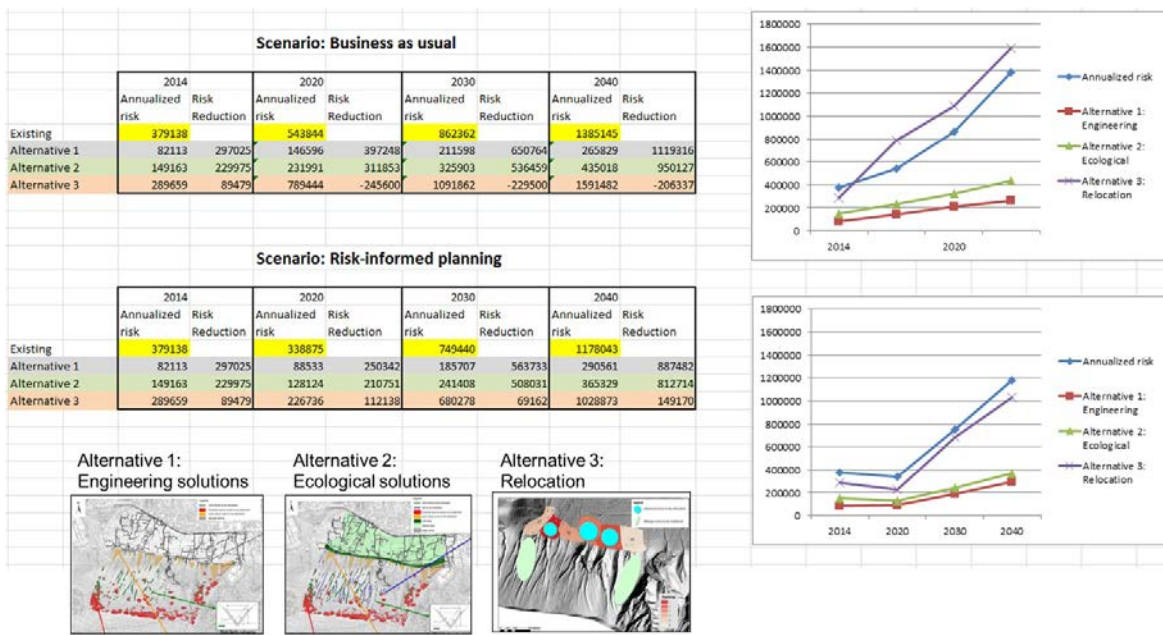


Figure 14: Application of the SDSS for a dataset from Italy, used a demonstration dataset. Here the results are shown for the risk reduction resulting from the implementation of three possible risk reduction alternatives for two possible future scenarios.

## 5.2 Fella area dataset.

Also the Fella area dataset was uploaded in the system, as one of the examples of datasets from the WP 2 work packages. Unfortunately it was not possible to use the other datasets from other case study areas in the system, due to the following reasons:

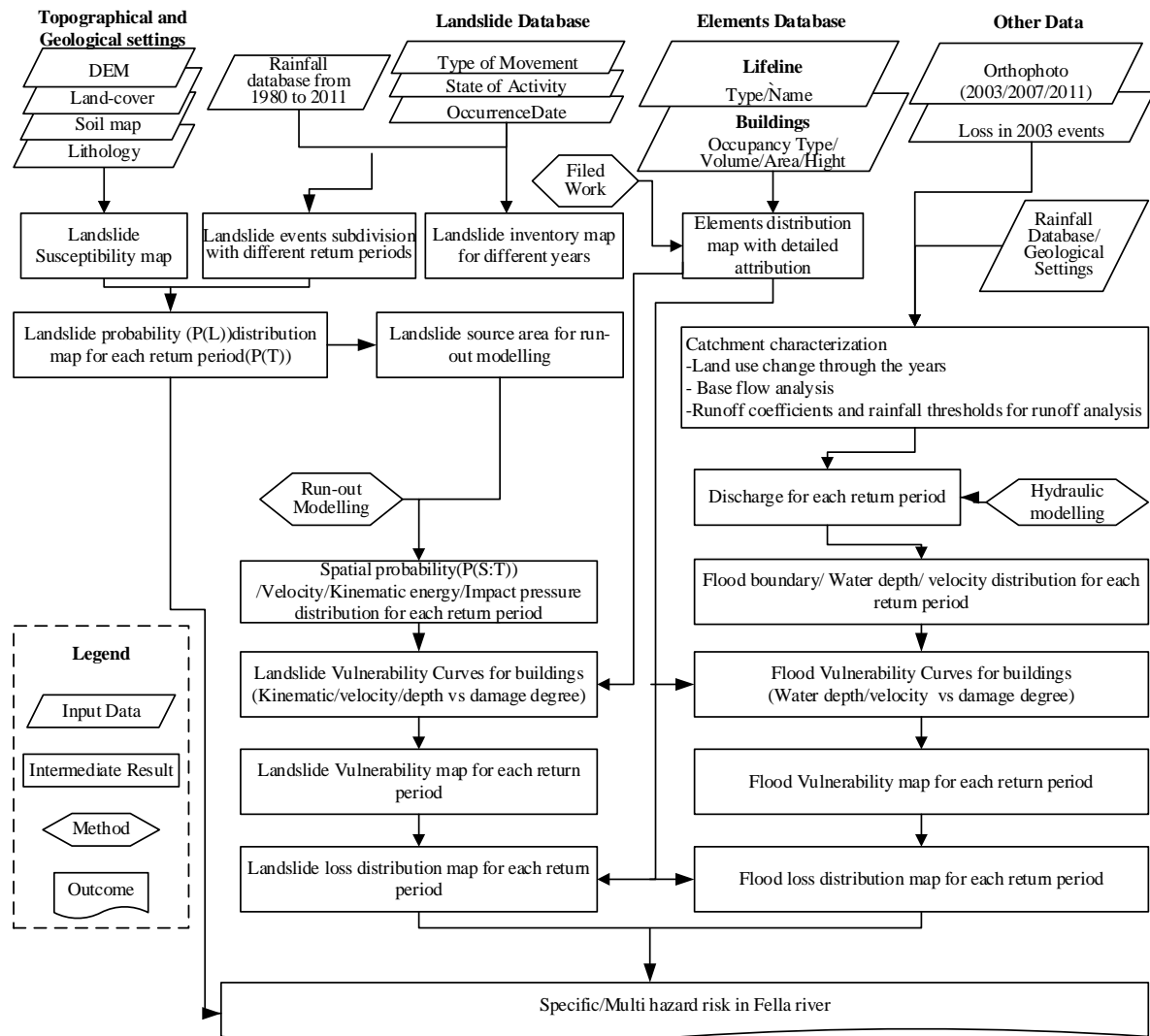
- The uploading part of the system was completed only at the end of the project, and due to time restrictions it wasn't possible to upload the other datasets;
- Many of the other datasets didn't really include actual hazard information, which should consisted of intensity maps for different return periods, elements-at-risk data with information on types, values and number of peoples.
- None of the datasets from the case study area contained information on possible risk reduction alternatives or possible future scenarios.

The flow chart of the methodology for the Fella area is shown in Figure 15. In order to support the local government to better manage and reduce hazard risk, the quantitative multi-hazard risk assessment was carried out using a historical landslide inventory and GIS modelling.

Based on historical landslide inventory data and rainfall events from 1976 to 2011, the return period for each class of hazard events was determined with extreme value distribution analysis with daily rainfall and 40 days accumulative precipitation. The catchment characterization was carried out based on the geological, topographical and rainfall data. Discharge for each return period was calculated by means of base flow and run off analysis. Based on this process, flood boundaries, water depth, and velocity maps were obtained for three return periods through hydraulic modelling with Hec-RAS. Flood risk assessment was then conducted by using overlay of a series of modelled flood intensity maps for different return periods with building footprints and vulnerability curves obtained from the literature. A flood loss estimation was subsequently carried out using GIS.

A landslide hazard map was generated from a five-class landslide susceptibility map and rainfall event magnitude. Run-out modelling was carried out by using Flow-R software, a modelling software that uses a GIS empirical distribution model to probabilistically estimate the flow path and run-out extent of gravitational mass movements at regional scales. Four steps were conducted for the model: (1) Source area identification; (2) Parameterization of the run-out model; (3) Debris flow hazard intensity modelling; (4) Spatial probability calculation. By using the Weights-of-evidence method, a five class susceptibility map was generated based on five factors including lithology, land-cover, altitude, plan curvature and slope. The susceptibility map was utilized as the source area selection for the landslide run-out modelling in the Flow-R software to generate intensity indicators (kinematic energy as indicator of impact pressure). Areas with very high susceptibility were then chosen as one factor for landslide initiation source area identification, which is required as an initial input for run out modelling in Flow-R software. Besides this, a criteria set is required in order to determine the pixels that are chosen as source areas to release the flows on the DEM. The criteria were chosen partly based on previous studies but were also updated specifically for the Fella River basin. Planar curvature lower than  $-4/100 \text{ m}^{-1}$  and slope values above  $15^\circ$  was then added as the other two determination factors for source area identification. Historical landslide areas belong to different event scenarios were finally added. Two parameters were required to model the run-outs for each return period in the Flow-R model: (1) the minimum travel angle and (2) the maximum velocity. These two parameters were back calibrated based on 1 or 2 historical landslides for each event scenarios. The back calibration included 2 sets of parameters, a minimum and maximum for each return period in order to include uncertainty in the parameter values which is translated in an uncertainty range in run-out extent and probability values. The method is further explain by Hussin et al. (2014).

The spatial probability of the debris flow hazard areas was determined by overlaying the modelled debris flow areas with the actual debris flow inventories that correspond to these return periods, and for those areas that were not affected by historical debris flow a spatial probability was calculated as the ratio between the historical inventory areas and the modelled areas, resulting in lower spatial probabilities for lower return periods that have fewer debris flow events. For the modelled flood intensity areas, and for the areas that were affected by historical debris flows, a spatial probability value of 1 was used. Vulnerability curves were generated, partly based on available curves from the literature, and partly based on actual damage information from the 2003 event, combined with expert opinion. Curves were made for debris flow impact pressure, and flood water depth, for 8 building types (which are a combination of the material type and the number of floors). Curves were made for the physical vulnerability for buildings, and for population. The hazard intensity data for each building and hazard return period in combination with the vulnerability curves were used to convert them into vulnerability data. Losses were then calculated for each building and hazard return period by multiplying the vulnerability, the spatial probability and the amount. The amount is related to the minimum and maximum building values in the case of economic losses, and for the minimum and maximum number of persons per building (taking a normal scenario and a tourist season scenario) to calculate the population loss. The risk was analysed by aggregating the loss data per building, and hazard return period for administrative units within the study area, and for the entire study area (which includes the towns and villages between Pontebba and Ugovizza). Minimum values for temporal probability ( $1/\text{return period}$ ) were used in combination with minimum values of loss (multiplying minimum values of intensity, and amount) to generate minimum risk curves, and maximum values to generate maximum risk curves. The multi hazard including landslide and river flood was analysed by comparing or combining the risk results of these two hazard types. After overlaying these two risk maps under each return period, the risk value was then calculated for each building. If one building was influenced by both these two hazards, the maximum risk value of both was taken. After this combination, the multi hazard risk was generated as risk curves and risk maps by administrative units.



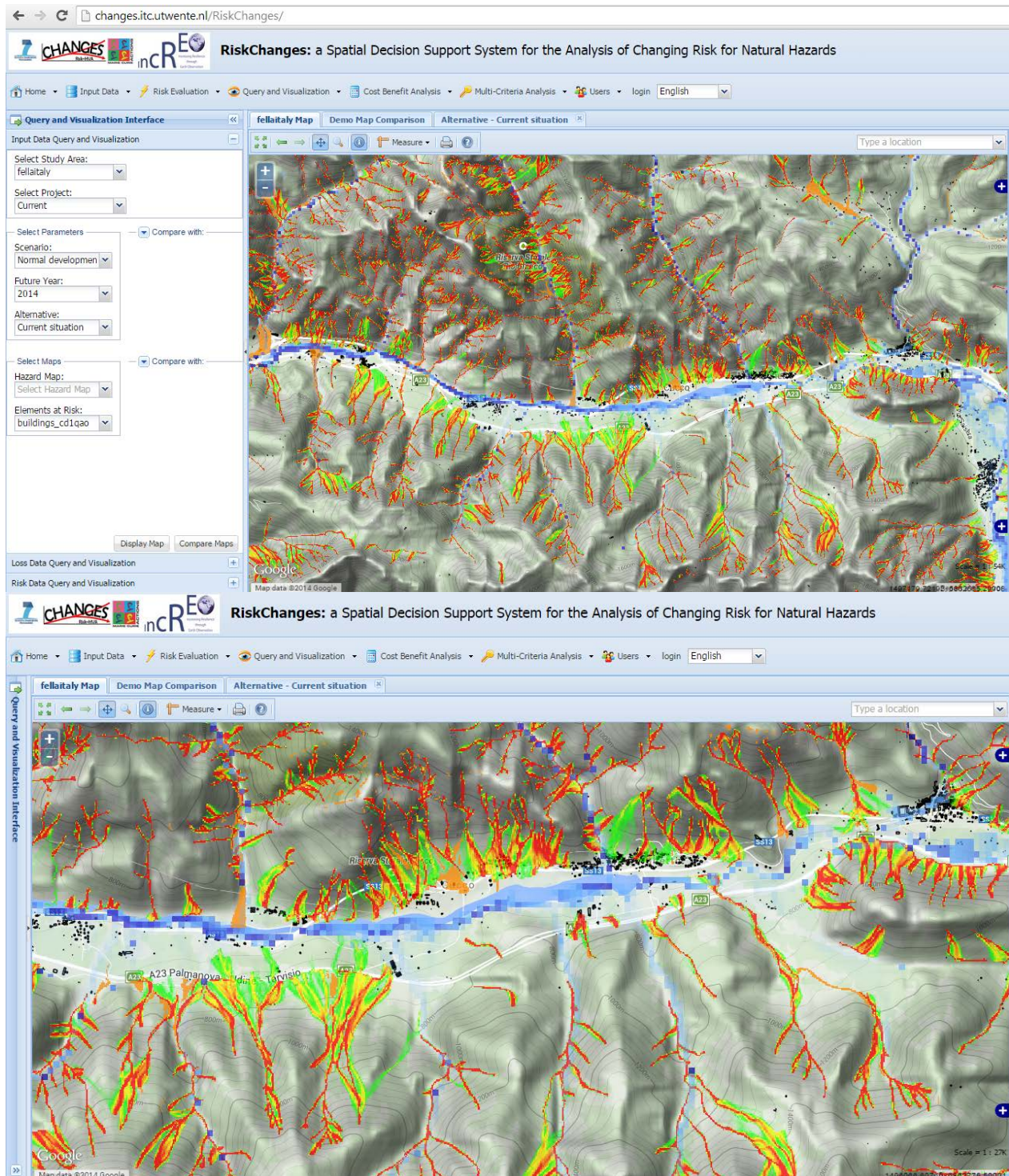
*Figure 14: Methodology for multi hazard risk assessment in Fella Basin, Italy*

Figure 15 shows some of the datasets from the Fella area, as they were uploaded in the SDSS. The Figure shows a combination of one of the debrisflow scenarios (maximum debrisflow runout modelled for a major event ) in combination with the flashflood modelled for the major event of the 2003 flood, and in combination with the exposed elements-at-risk.

Quantitative risk information can be an important basis for hazard risk mitigation and other management measures in Fella River, Italy. In addition, debris flow potential influence area, intensity and flood inundation area or depth can also be indicators for land use planning in such meteorological hazard prone areas.

Due to the limitations in scale and quality of available soil data, flash food modelling could not be carried out at a satisfactory level in this study. Debris flow run-out modelling results shows a good performance for the potential influence area, but not well for intensity distribution. It will be improved by further analysis based on geological condition classification, and further calibration and comparison of regional scale run-out modelling with local scale analysis. Further work is also needed to generate more reliable vulnerability curves for debris flows and flooding in an alpine setting. But because of the time limitations, the curves were taken from literatures which may be not very suitable for the elements-at-risk in the area. Back analysis will be carried out later aiming at improving vulnerability curve definition based on historical damages and debris flow run-out modelling. Thus, hazard intensity and more suitable vulnerability curves can therefore contribute for more reasonable economic or population risk results.





*Figure 14: Application of the SDSS for a dataset from the Fella case study area in Italy, where debris flow data was used in combination with flood hazard data and buildings as elements-at-risk.*

## 6. Further Development of the SDSS

In the past 2 years we have been developing the RiskChanges spatial Decision Support system, which is a web-based system for the analysis of changing risk to natural hazards as a consequence of risk reduction planning and/or possible future scenarios for climate change and land use change. The development was funded by the EC through two EU FP7 projects (CHANGES and IncREO). For the CHANGES project we hired 5 programmers for 18 months, which were based in 5 different partner Universities (Twente, Delft, Dortmund, Lausanne and Salzburg). From the IncREO project we were able to fund the time for the design and coordination of the system. Coordinator of the project was Cees van Westen. Wim Bakker was involved in the coordination of the technical development. Luc Boerboom and Emile Dopheide were involved in the design of the cost-benefit analysis, and multi-criteria evaluation modules.

The system is nearly complete as a prototype, and can be assessed through: <http://changes.itc.utwente.nl/RiskChanges/>

We have demonstrated the system in various international conference and workshops, and have received very positive feedback from potential users. On 18 and 19 November the system was demonstrated during the final conference of the CHANGES and INCREEO project, where 150 participants are expected, and which is co-organized with organizations like EGU, UNESCO, and UNEP (See: <http://www.changes-itn.eu/Conference/tabid/132/Default.aspx> )

We have also demonstrated the system to the World Bank team which whom we are doing the CHARIM project in the Caribbean and they indicated the potential of the system to be used in different parts of the world as a tool for risk assessment and risk reduction planning. A letter of support from the World Bank is attached. Also in discussions with the Red Cross they showed interest in the use of the system in different areas. So we believe the system has a great potential.

Although most of the above mentioned modules have been developed, there are still a number of aspects that could not be implemented up to now:

- The system works completely with a demo dataset that illustrates all steps in the analysis, but the uploading of new datasets is still not fully implemented;
- The user management of the system should still be implemented, which is essential if other users are going to use the system for their own study areas;
- Bug testing of the system has not been carried out systematically, and should still be done;
- The multi-criteria decision module has not been completed, and more work is needed to complete the component;
- Documentation of the system is still required;

For the completion of the RiskCHANGES Spatial Decision Support System we have made the following workplan with an estimation of tasks and time from January to July 2015. One of the developers of the system (Kaixi Zhang, who was hired in the CHANGES project for 18 months and who did a marvellous job) will be hired for another 6 months, and also some freelancers will be involved to carry out the following tasks:

### 1. Complete the Vulnerability module ( 1 month)

Create vulnerability database and changes in python code: a vulnerability database enable users to share vulnerability data. Changes in the database, all related python codes are required since currently vulnerability data in the system could not be shared.

Vulnerability input, delete and edit functions: instead of importing vulnerability files, users could create vulnerability by hand, edit and delete vulnerability values.

**2. Add function all visualization button in the system (2 weeks)**

within data input, loss and risk modules (1 month): for example, instead of using visualization query modules, users could visualize the uploaded maps directly when the uploading process was finished.

**3. Dynamic styling of Hazard and Elements-at-Risk (2 weeks) :**

dynamically create styling file of each map based on the values or classes within the map.

**4. Modify Loss and Risk UI to be more user friendly (1 month) :**

for instance users could know which loss was computed or not.

Allow dynamic use of the dashboard, that works in simple and complicated cases

**5. Test the system using different data sets (total 3 months)**

Import other data within the system (Fella area, Caribbean data for the World Bank): prepare the data in the required format, import data through data input module, fix bugs in data input module.

Test and fix bugs: fix bugs in the various modules (Risk, CBA, MCE and Visualization).

**6. User Management module (1 month)**

Data model design for User Management module

User Management UIs design and implementation

Server side functions to create, edit and delete users within the system

Add codes to check username and password in all the functions in each module (Data Input, Risk, CBA, MCE and Visualization)

**7. Complete data uploading and improve the data input user interface (2 months):**

Finalize the database structure and check for use of different data sets

Simplify the user interface for data uploading

Simplify the link with vulnerability curves. Currently users have to repeat the process of selecting vulnerability curve for each Element-at-risk code type. Efficient way has to be made to avoid redundancy.

**8 Further improvement in the cost-benefit and multi-criteria modules (1 month)**

Improve and simply the user interfaces for these two modules.

**9. Documentation (2 months)**

Adding help to the various components of the system

Writing a Users Guide

Source Code publishing and documentation

## **ACKNOWLEDGEMENTS**

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