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

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Abstract
Within the framework of the EU FP7 Marie Curie Project CHANGES (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.

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 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.

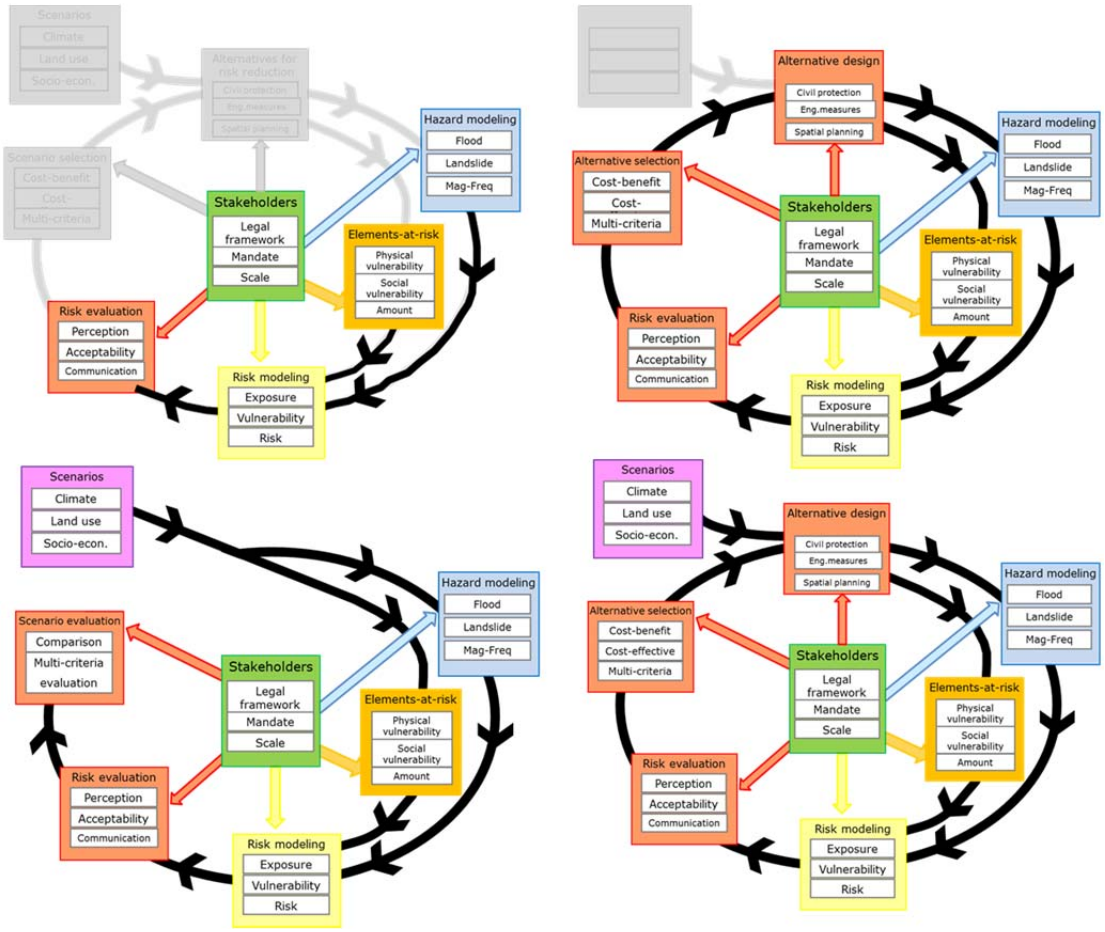

*Figure 1: Different uses of the RiskChanges SDSS. Different colours refer to different components: **green** = stakeholders, **Blue** = organizations responsible for providing hazard maps. **Orange** = organizations responsible for providing elements at risk maps, **Yellow** = organizations responsible 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.*

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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

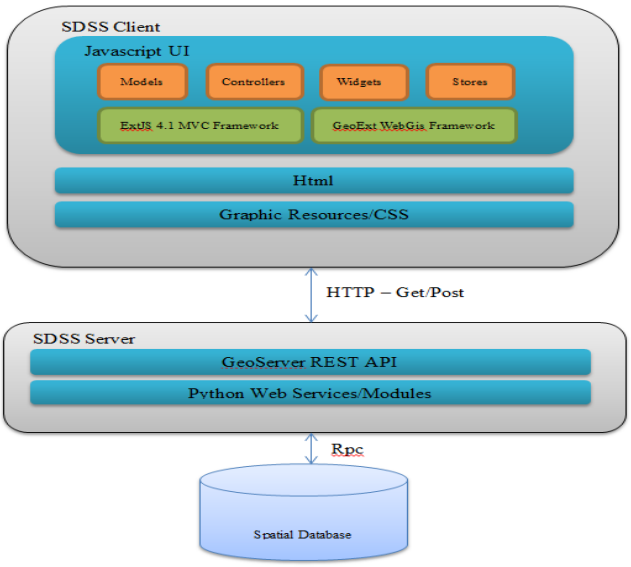

Figure 2: The system architecture

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. minimum and maximum) or people (e.g. daytime or nighttime scenarios) can be included, which allow the users to calculate the range of economic and/or population risk.

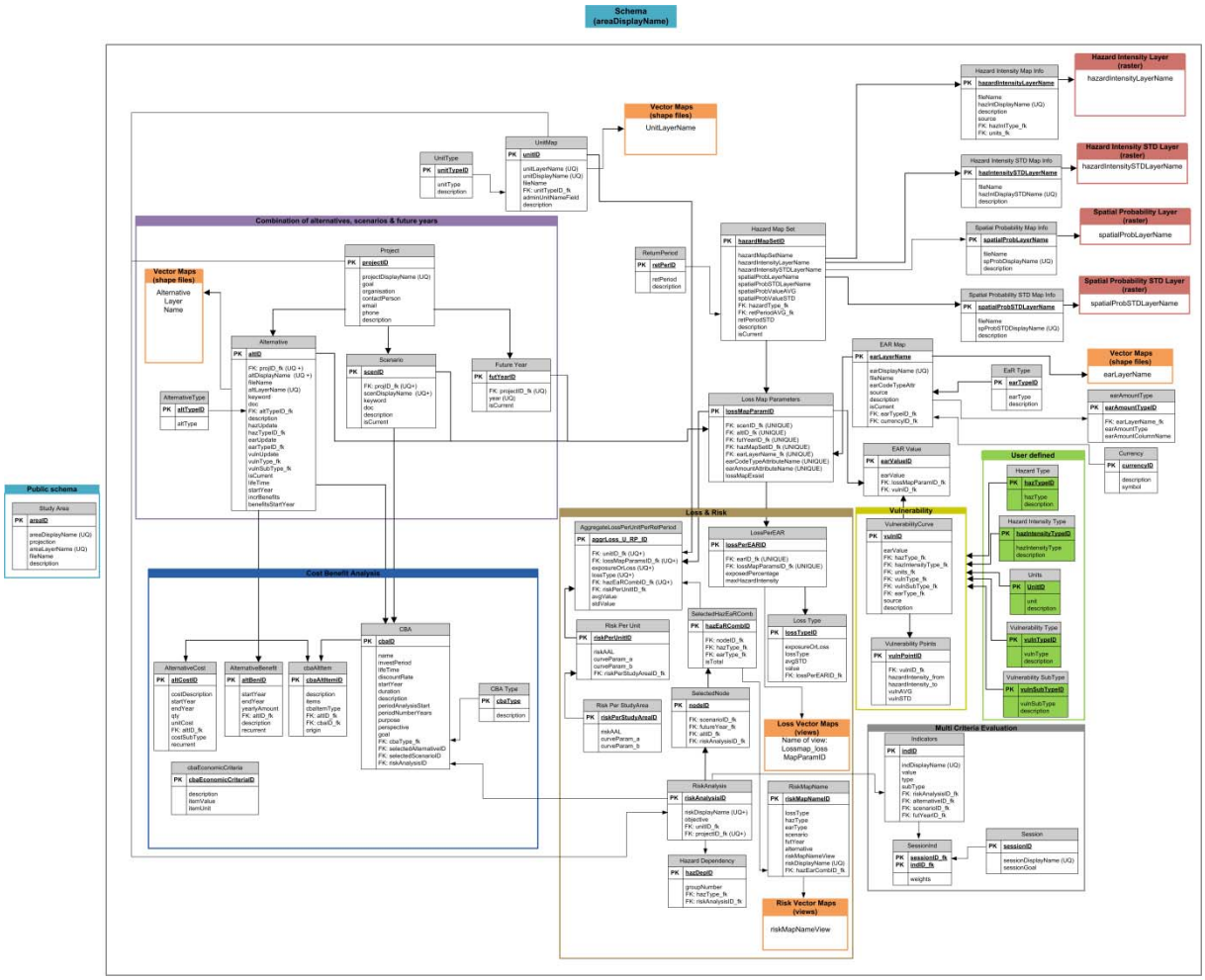

Figure 3: Data model with the various components of the system. Purple: the projects that determine the alternatives and scenarios; Orange: the spatial layers (elements-at-risk, hazard, loss and risk data); Red: Hazard data sets; Green: Vulnerability data; Ocre: Loss and risk attribute data; Blue: cost-Benefit data.

Vulnerability data is managed in the system using vulnerability curves in the form of tables, which can linked to the construction types in the elements-at-risk tables. Furthermore, the model handles information about administrative units, for which the risk is calculated.

The user has to create a project when he wants to formulate certain risk reduction alternatives and/or future scenarios. Alternatives are various options that could be implemented to reduce the risk and where the user has a choice option, to decide which one of the alternatives is the best. The user has to define how hazards, elements-at-risk and vulnerability might change as a consequence of a certain alternative, and has to upload new maps if the situation will change. This means that alternatives that would only change the location of elements-at-risk (e.g. relocation) would require only a new element-at-risk map, whereas alternatives that also change the hazard (e.g. checkdams or dikes) would also require the uploading of new hazard maps.

Scenarios are possible future trends resulting from changes in land use and/or climate change. These are evaluated for a given number of future years, which the user has to define. For each of these future years new hazard and elements-at-risk have to be uploaded. The system does not simulate future changes in hazard or elements-at-risk.

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 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.

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.

The system is online, and can be accessed through the following URL:
http://changes.itc.utwente.nl/CHANGES-SDSS/
The start page of the system is shown in Figure 4. The following chapters will give an overview of the different modules.

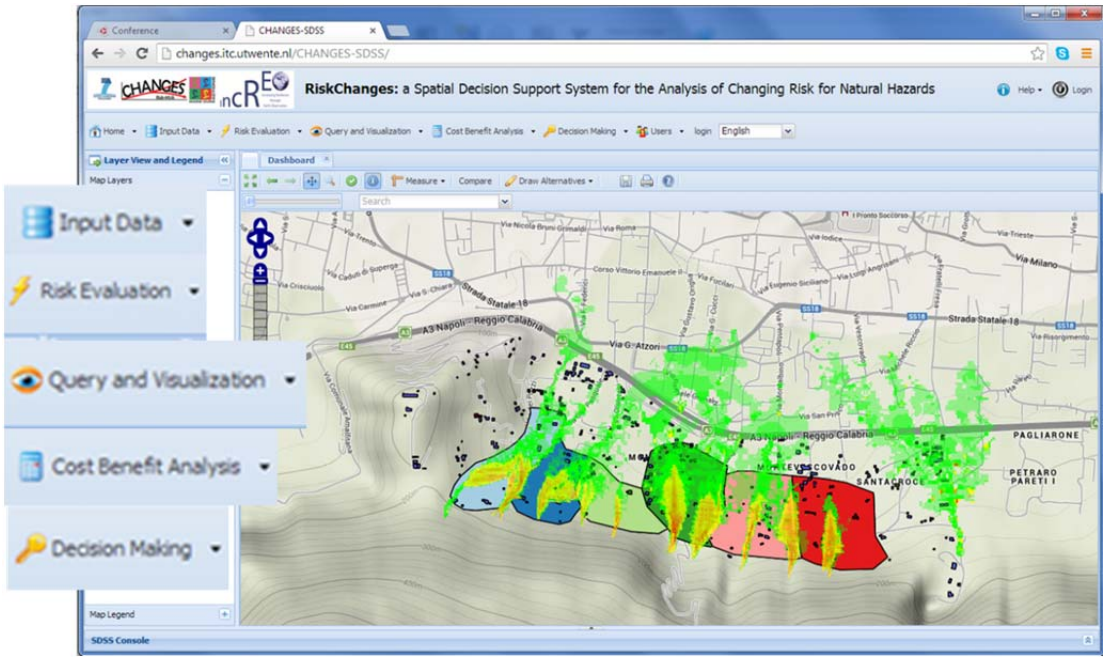

Figure 4: Opening screen of the RiskChanges SDSS.

DATA INPUT MODULE

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

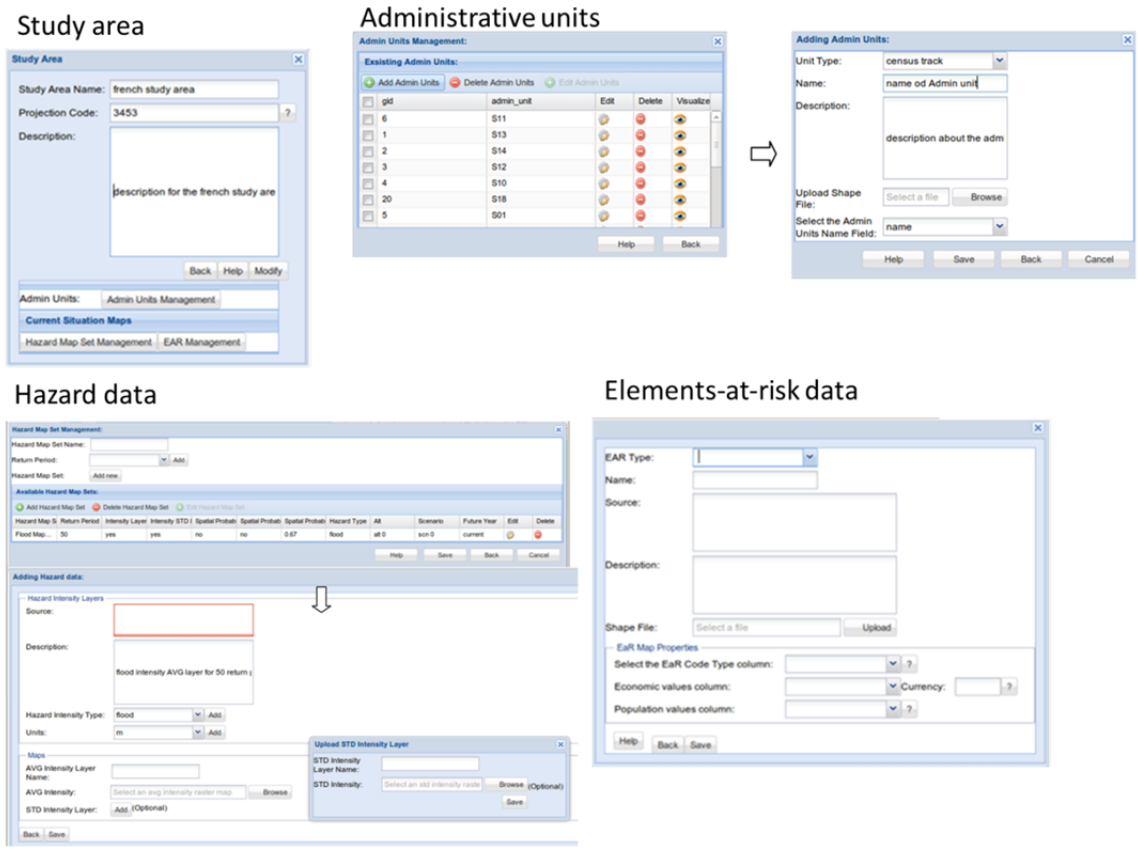

Figure 5: User interface for the data input of a study area, with hazard data and elements-at-risk data

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 alternatives (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).

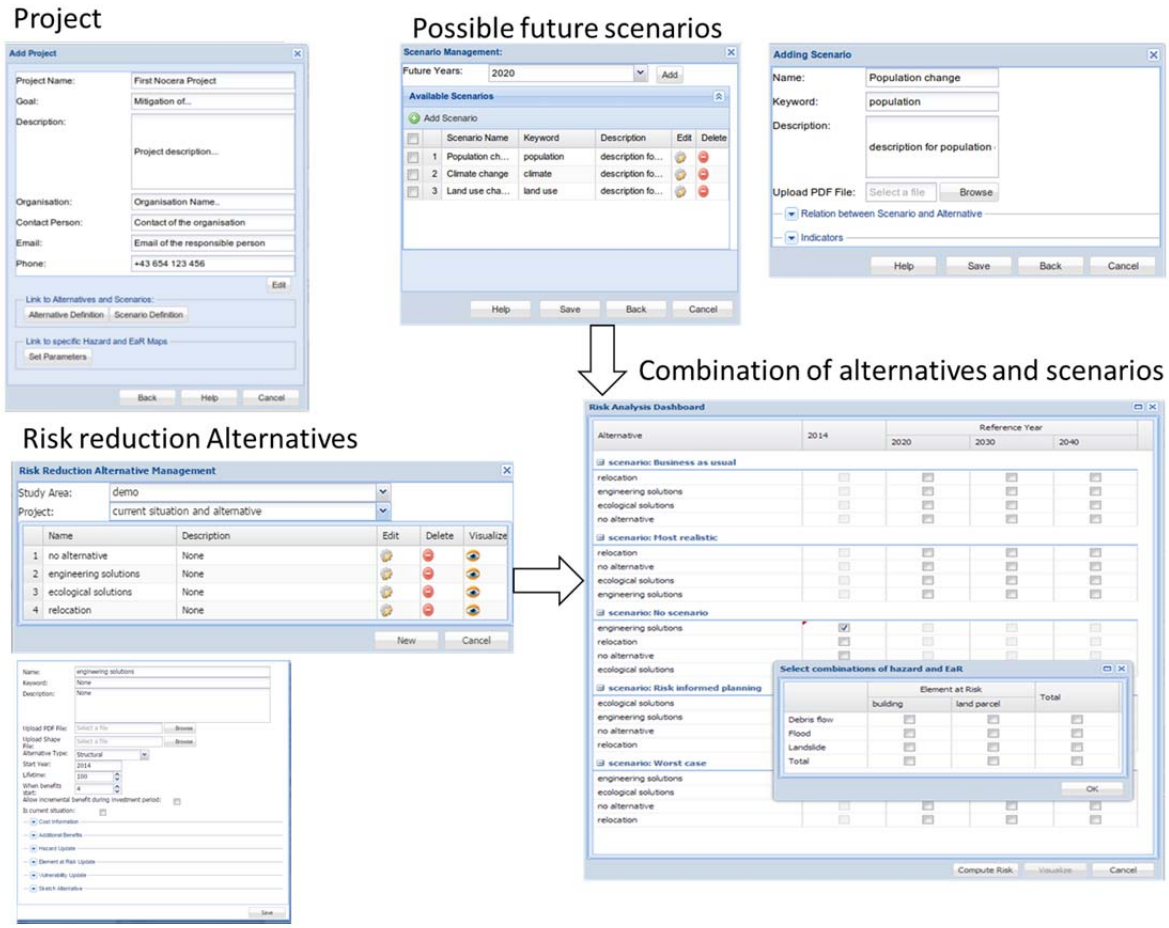

Figure 6: User interface for the data input of a project, with alternatives and scenarios

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.

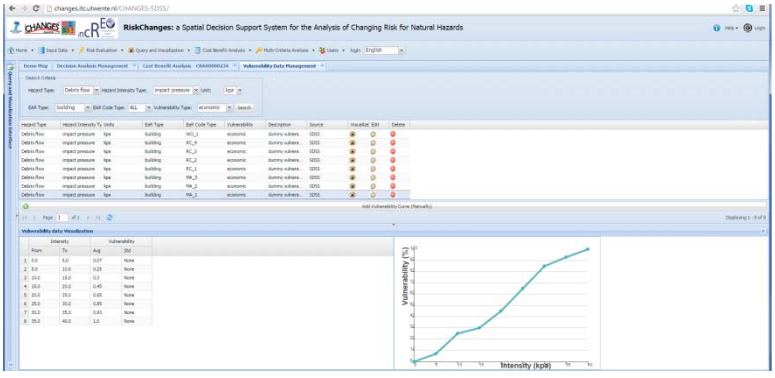

Figure 7: Vulnerability curve management within the system.

LOSS ASSESSMENT AND RISK ASSESSMENT 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 indivdula 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.

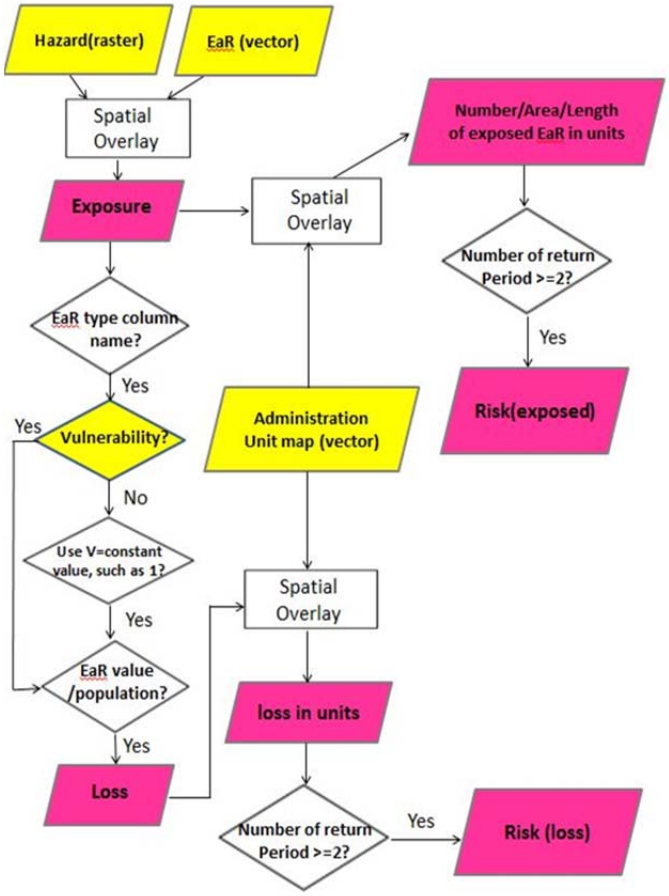

Figure 8: Flow chart of Risk assessment module. The box filled by yellow color indicates the input data, while the ones in red are outputs

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.

$$\text{Risk}=\frac{1}{T1}\square S1+\frac{\left(\frac{1}{T2}-\frac{1}{T1}\right)\square S1+S2}{2}+\frac{\left(\frac{1}{T3}-\frac{1}{T2}\right)\square S2+S3}{2}+\frac{\left(\frac{1}{T4}-\frac{1}{T3}\right)\square S3+S4}{2}+\frac{\left(\frac{1}{T5}-\frac{1}{T4}\right)\square S4+S5}{2}$$

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

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. 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.

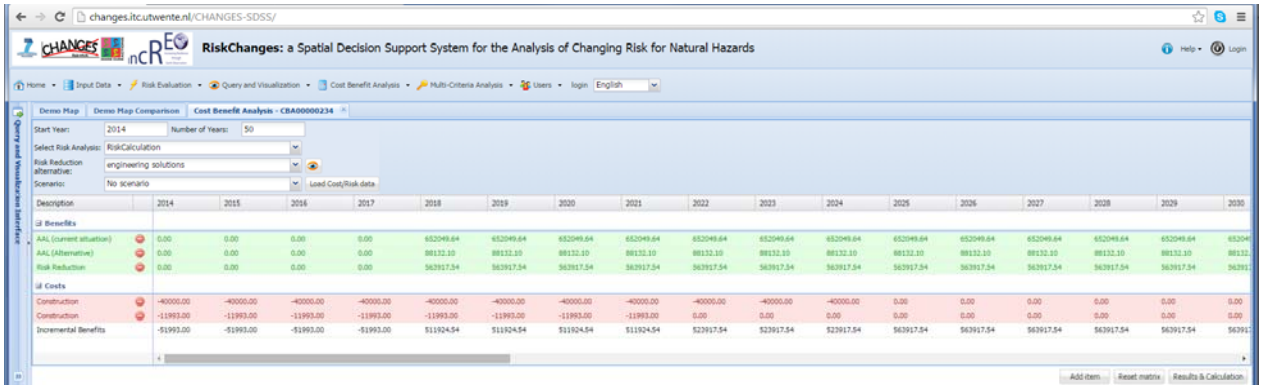

Figure 9: the structure of the cost-benefit analysis module, where users can indicate the costs and benefits for different risk reduction alternatives, in addition to the risk reduction calculated through the risk analysis module of the system.

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).

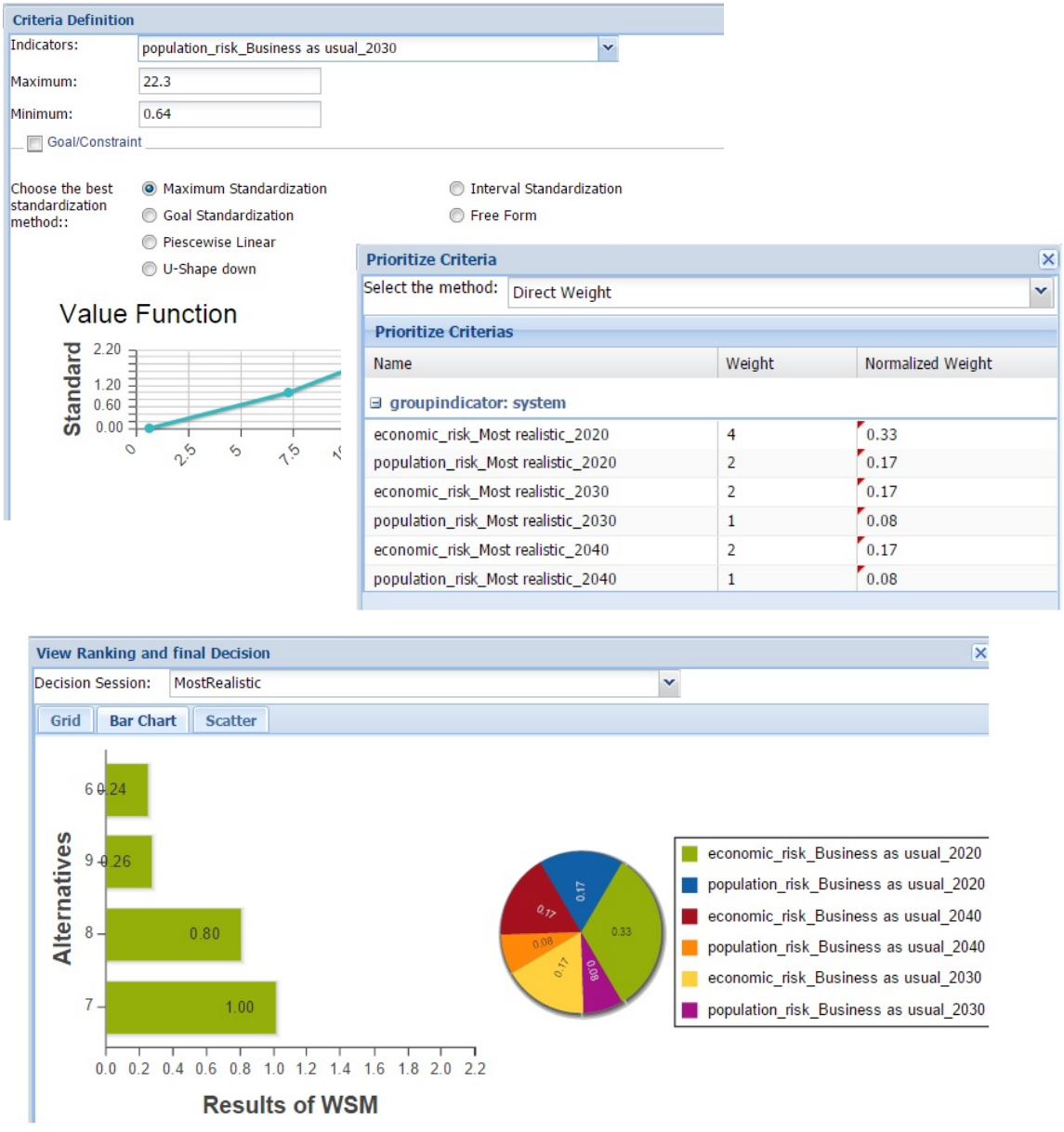

Figure 10: Standardization(criteria definition), prioritizing (weighting) criteria and ranking the alternatives: After analysing the risk after implementing the alternatives, the user can analyse the costs of the alternatives, and make a cost-benefit analysis, leading to a prioritization of the alternatives. 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.

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.

CONCLUSIONS

The implementation of the system turned out to be more complex than we anticipated. Although most of the above mentioned modules have been developed in principle, 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 and further documentation of the system should still be done;
- Host the system on a server with sufficient speed, security, and capacity outside;

ACKNOWLEDGEMENTS

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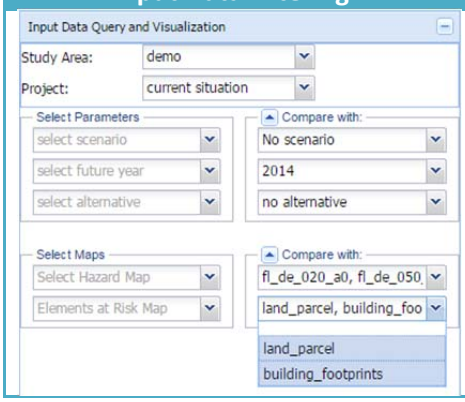
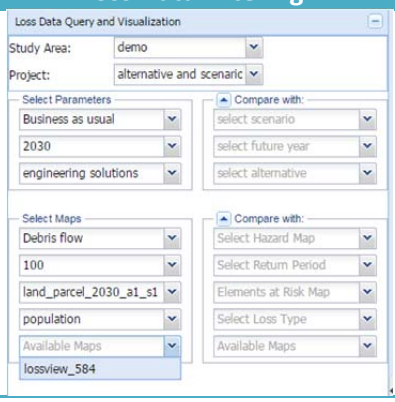
Data Filtering

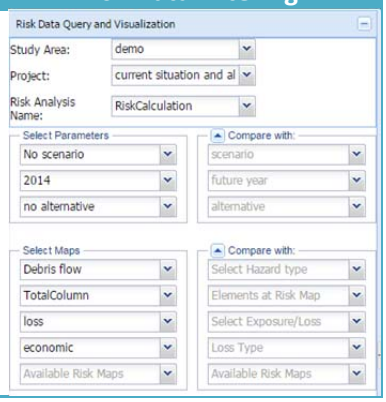
Input Data Filtering



Loss Data Filtering

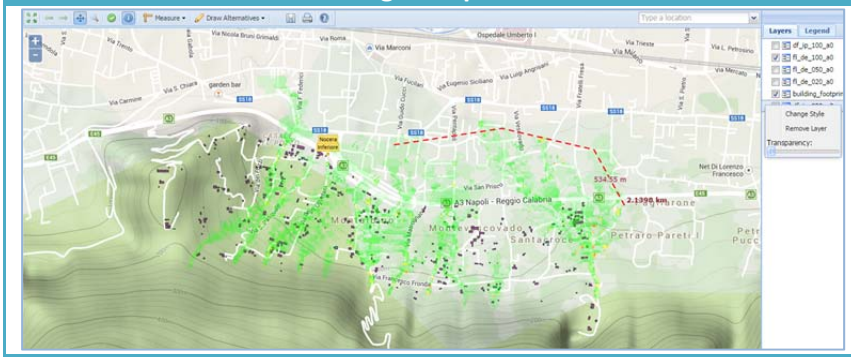


Risk Data Filtering



Single Map Visualization

Web-GIS: Single Map Visualization

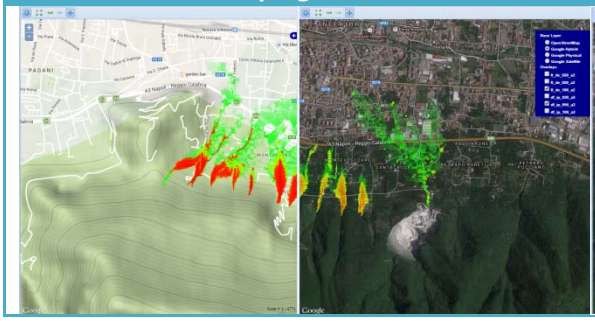


Functionalities

- Basic GIS tools (navigation, geo-location, measurement tool etc.)
- Feature Info
- Layer tree
- Context Menu
- Map Legend

Data Comparison

Swiping tool



Linked views

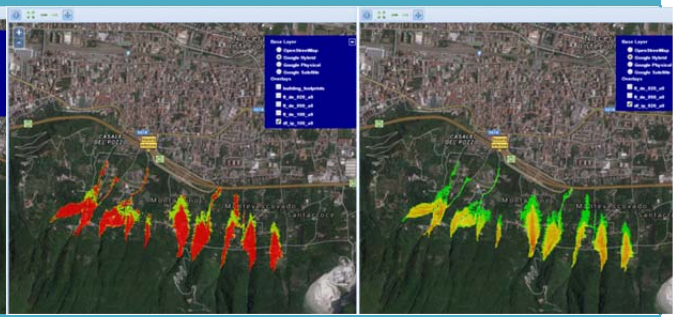


Figure 11: Different components of map visualization is the RiskCHANGES SDSS