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Web-based risk assessment techniques for hydro-meteorological hazards

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INTRODUCTION

Risk assessment is very crucial in aiding decision makers about how to manage and minimize risks by applying a science-based and systematic approach to quantify risk. To address in this context easily and promptly sharing and utilizing risk data, the web based spatial decision support system 'RiskChanges' is currently under development to analyze changing hydro-meteorological hazards and the effect of risk reduction alternatives to support decision makers in choosing the best alternatives. The risk assessment component within the system is 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 (Van Westen, 2014).

The input data required by this component, including hazard maps combined with Elements-at-Risk (EaR) and vulnerability, are provided by external organizations or entered by the user through data input component. The outputs of risk assessment component are the basis for cost benefit and multiple criteria evaluation components. Moreover, the loss and risk maps and curves could be visualized by the component Visualization.

METHODS

The risk assessment component 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 ear maps made by users, e.g. loss_building_under_flooding_20yr. 4 steps should be conducted to compute loss: firstly overlay hazard intensity layer and spatial probability layer with EaR layer, then compute intensity and spatial probability for each EaR, retrieve vulnerability value for each EaR based on the hazard type, EaR class and the intensity value the considered EaR is exposed, finally the loss computed as the product of EaR economic value (or population number), vulnerability and spatial probability. It should be highlighted that the loss estimation module can only be executed after finalizing the data Input through another component within the system.

On the other hand, the risk analysis module calculate risk using the outputs of 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 different 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.

Flow chart

As shown below in Figure 1, the outputs that can be generated by this component totally depend on what data they input within the system. The necessary input data required are hazard layers which are raster based and EaR layers which are vector, while the optional ones include vulnerability values and administration unit maps. In principle, 6 possible outputs could be computed:

1. Exposure: compute whether each EaR is exposed in hazard if user input hazard maps and EaR maps
2. Number/Area/Length of exposed EaR in units: aggregate the exposure element in each unit if exposure is computed and an administration unit map is specified. If EaR type is building or point, the exposure element should be the number of exposed buildings or points. If EaR type is land parcel, the exposure element then is the area of exposed land parcel. Otherwise, the exposure element is the length of exposed line if EaR type is line element like road.
3. Risk (exposed): annualized risk of exposed number/area/length could be computed if exposed information in units is produced and more than 1 return period is existed for a hazard type.
4. Loss: calibrate economic or population loss of each EaR if user provide hazard maps, EaR maps, but also indicate EaR type column which is a column name in EaR layer containing EaR class types and EaR value column which is a also column name in EaR layer describing how much is each EaR or how many people stay/live in each EaR. Besides, the vulnerability curves should be specified.
5. Loss in units: aggregate the loss values of all EaR in each unit if the loss value has been computed an administration unit map is specified.
6. Risk (Loss): annualized risk of loss if loss values in units area derived and more than 1 return period is existed for a hazard type.

Design and implementation

The risk assessment module is developed using Ext JS library for the implementation of user interface on the client side, using Python for scripting, as well as PostGIS spatial functions for complex computations on the server side. The outputs of this module depend on users input.

RESULTS

Figure 2 shows the webpage of our system. The menu 'risk evaluation ' in the main toolbar is the start point to conduct risk assessment component. Under this main menu there are two sub menu 'loss' and 'risk' representing the loss estimation and risk analysis module individually. Hereby, this section introduces the user interfaces designed for each module and how the functionalities are implemented in detail.

Loss estimation module

After clicking the 'loss' sub menu in the main toolbar, a new window named 'Loss Estimation' pop up. It can be seen in Figure 3 that users should firstly select the study area they want to

compute loss there. After the study area is specified, all the project names under that study area will appear in the project combobox for users to select. It is the same that all the scenario, future year and alternative will be shown in the corresponding combobox if users specify the desired project.

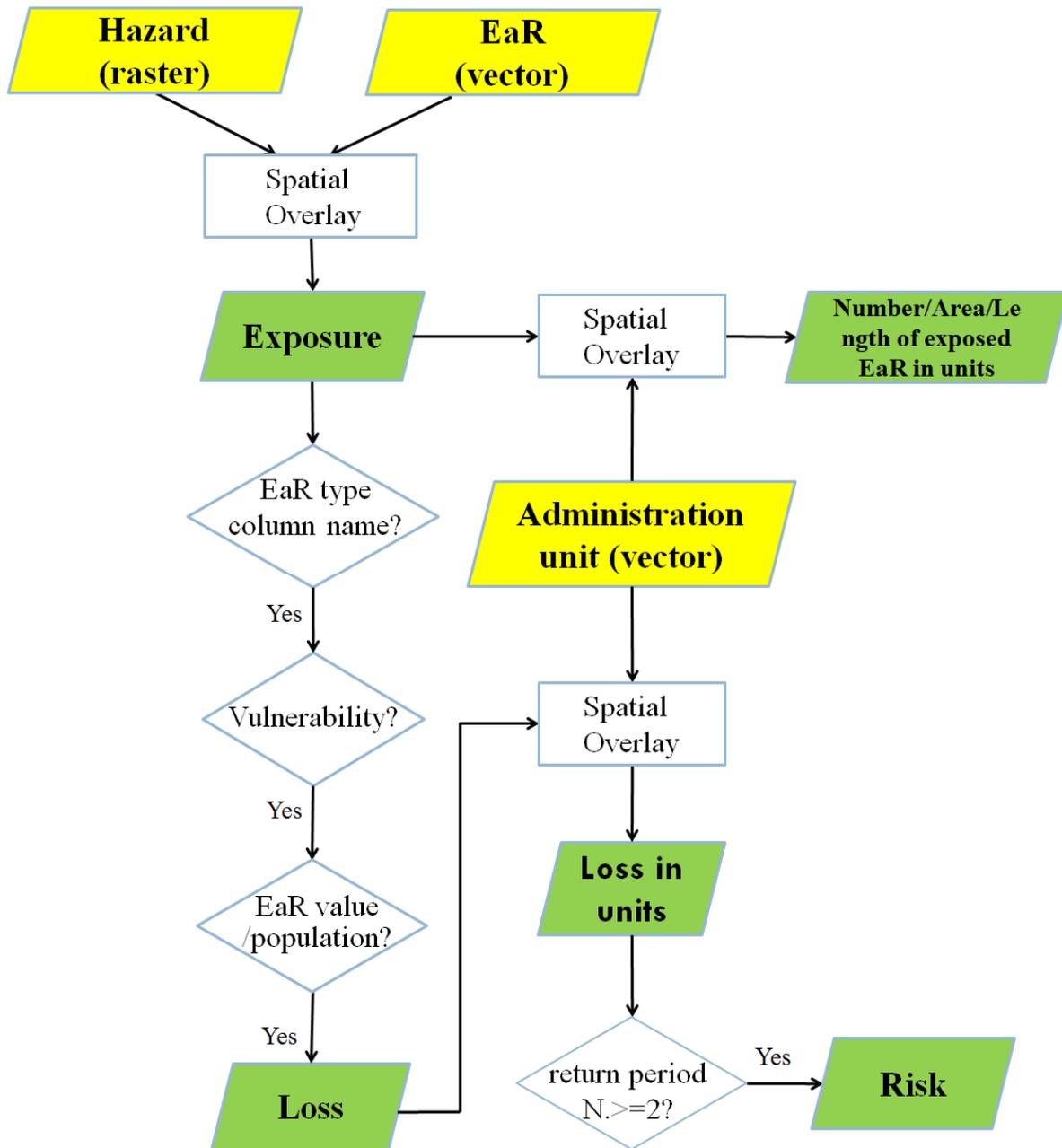


Figure 1. Flow chart of Risk assessment component. The box filled by yellow colour indicates the input data. the ones in green are outputs

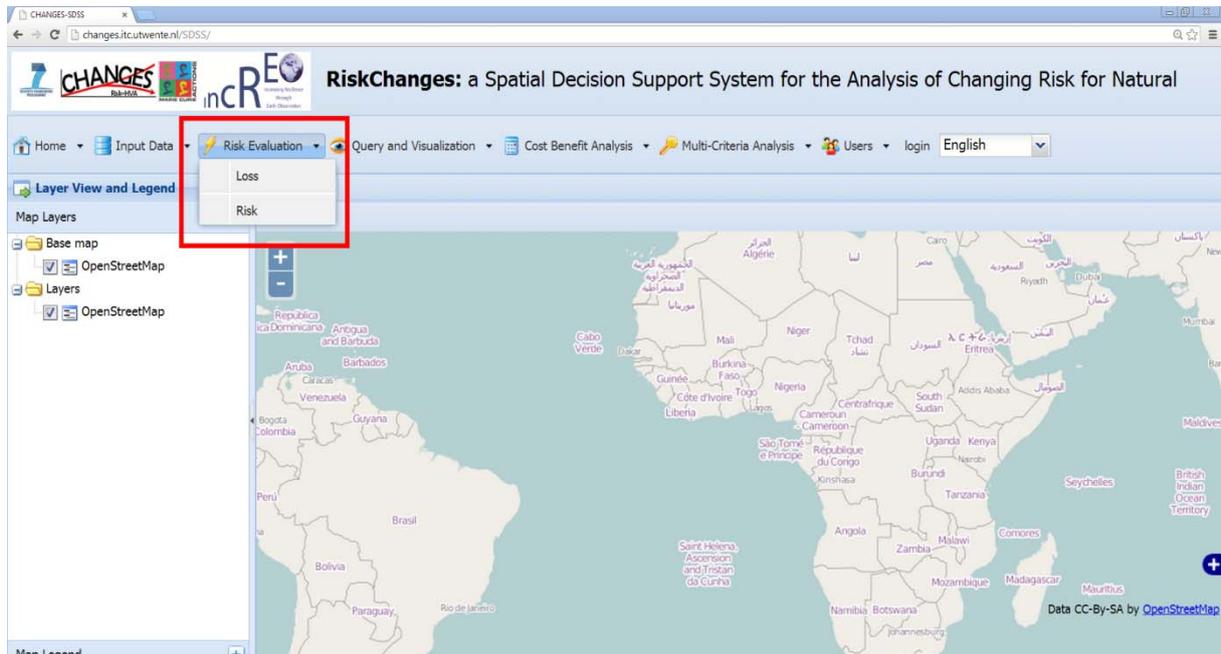


Figure 2: The main menu of risk evaluation component in the Changes SDSS web page

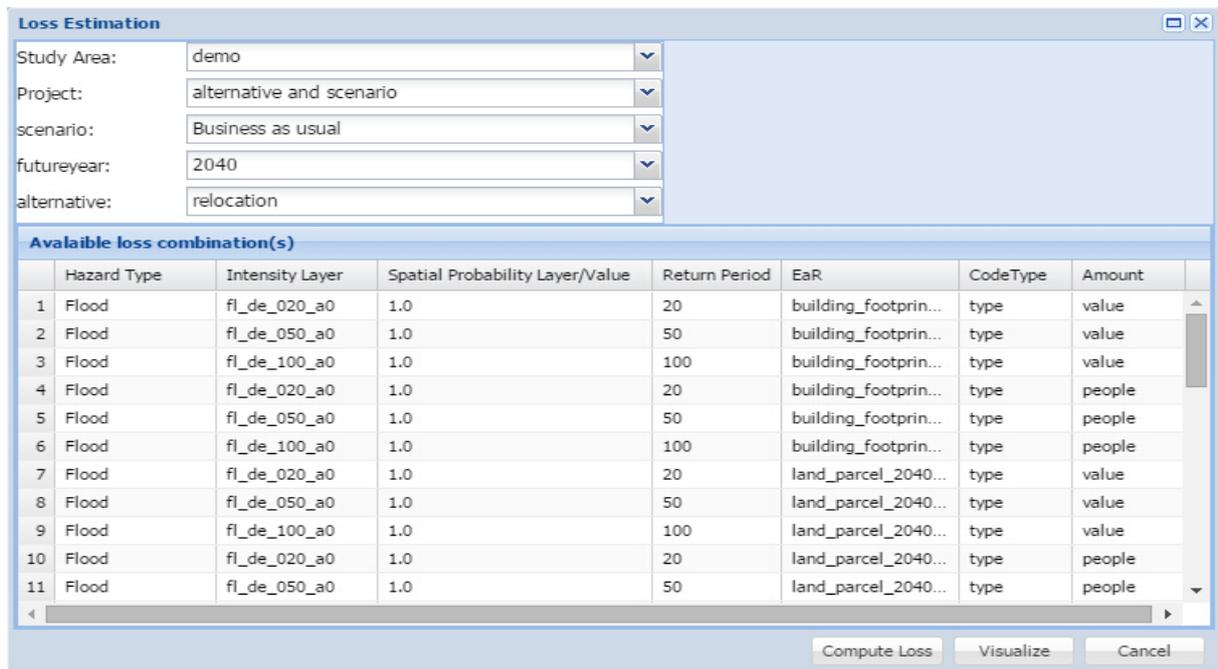


Figure 3: Loss estimation user interface after users input

Once all the combobox contents are filled, all the loss combinations between hazard maps and EaR maps under the selected study area, project, scenario, future year and alternative appear in a grid, as the example shown in Figure 3 above. These loss combinations are exactly the ones users made before in data input component. Take the first record in the grid for an example, it can be seen that the hazard type is 'flooding' with the intensity layer 'fl_de_020_a0' which has been imported in our database through data input component, the

spatial probability layer/value '1.0' and return period '20' years, and the EaR layer name is 'building_footprints' with a column name 'type' containing building class info and a column name 'people' containing the number of people in each building. Actually each record in the grid corresponds to a loss map. A button 'Compute Loss' is for users to compute loss maps for all the records as a batch. The produced loss maps can be visualized by clicking the button 'Visualize' which is connected with another component within the system.

As mentioned before, the hidden loss computation carried on the server side using python and SQL programming language consists of 4 steps: overlay Hazard with EaR, compute intensity and spatial probability, retrieve vulnerability value and finally compute loss as a product of vulnerability, spatial probability and quantity value. PostgreSQL/PostGIS provides spatial functions to perform the spatial functionalities such as 'ST_Clip()' to perform the clipping between raster and vector layers and 'ST_ReClass()' to classify the intensity pixel values based on vulnerability curves to get the corresponding vulnerability values. Besides, it should be pointed out that different methods are designed for different EaR types to retrieve vulnerability value.

1. **Building:** the maximum intensity value of an EaR exposed is used to search the vulnerability
2. **Land Parcel:** considering large size of a land parcel, a single intensity value cannot describe the situation in a land parcel. Thus after clipping the intensity pixels using the boundary of a land parcel, the intensity pixels are reclassified into vulnerability pixels based on the pixel value, land parcel class type and vulnerability table. The loss for the whole land parcel is equal to the summary of the loss of all pixels.
3. **Line Element:** A line EaR in a line element map is chopped into small segments. For each small segment, a buffer is created to generate a polygon and then clipped with hazard intensity map. Later the maximum intensity value in this new generated polygon is extracted and then used to query the corresponding vulnerability. The quantity of the considered segment could be computed by multiplying the quantity info of the whole line with the percentage of this segment in the whole line. The loss of the whole line can be the value summarizing the loss of all segments.
4. **Point:** Before clipping, a buffer is made for every point. The buffer size depends on the pixel size in hazard map. Then the clipping is conducted between the polygon geometry of a point buffer and hazard map. The maximum intensity value is extracted to query the vulnerability value.

Risk Analysis Module

The risk analysis module is flexible and is determined by users what risk are computed. Users have the option to create their risk analysis for a certain purpose. Figure 4 presents the risk analysis management user interface by clicking the menu 'risk' in the main toolbar. As same as loss estimation module, users have to select the study area and the project. After those operations, the already conducted risk analysis name and unit layer adopted are displayed in the grid. Users not only have the options to edit, or delete or visualize those existed risk analysis, but also can add new risk analysis as they want. If the button 'Add Risk Analysis' is clicked, a new window (Figure 5) pops up. Users can define the name and objective of the new risk analysis in the new user interface. A unit map with polygons for which the risk is calculated should also be indicated. The unit map can be administrative units (e.g. sections of the municipality), homogenous units (user defined polygons) or for the entire municipality. The risk values and risk curves are expected to be calculated for each unit in the mapping unit layer as well as the whole study area. It should be stressed that the risk analysis name, objective and mapping unit are necessary in defining a risk analysis, otherwise users could not go to the next step. Hazard dependency is used for multiple

hazards risk assessment. Users are able to click the 'OK' buttons in Figure 5 to get the next user interface risk analysis dashboard (Figure 6).

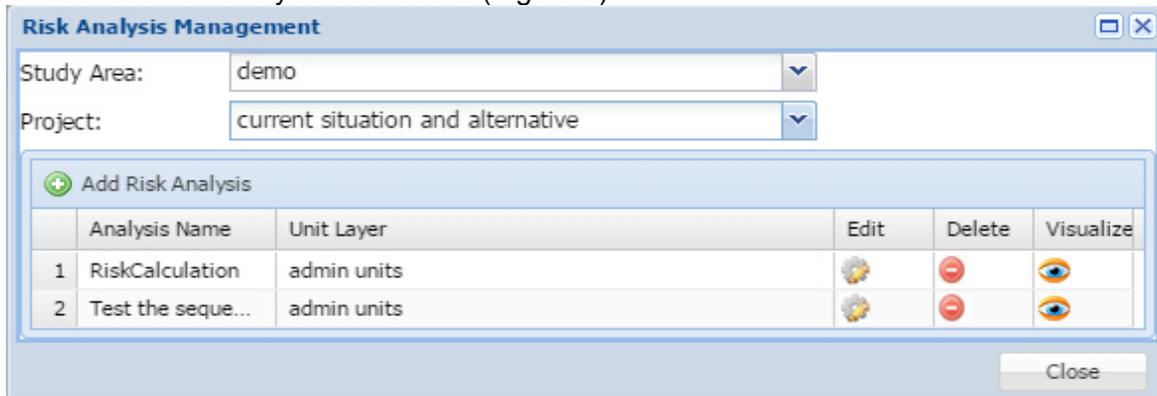


Figure 4: Risk analysis management user interface

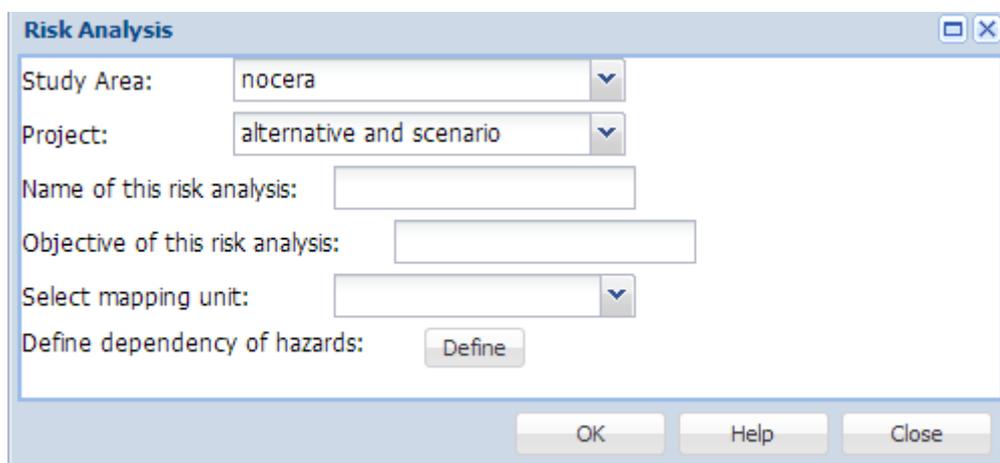


Figure 5: Create new risk analysis user interface

The risk analysis dashboard contains all the combinations of scenario, alternative and future year under the selected study area and project. As illustrated in Figure 6, each combination shown as a checkbox in the user interface. The disabled checkbox indicates that no input data, or no enough return periods available to conduct risk analysis under this combination of scenario, alternative and future year. When users tick the enabled checkbox, a pop-up window appears. Take the one shown in Figure 6 for an example, 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 hazard dependency users defined before is used in this computation. If users tick the checkbox with 'hazard' type 'Flood' and 'EaR' type 'Total, it means that the risk of all the EaR (building and land parcel in this case) under the hazard flood will be computed. If users tick the checkbox with 'hazard' type 'Total' and 'EaR' type 'Total, it means that the risk of all the EaR (building and land parcel in this case) under all the hazard types (flood, landslide and debris flow in this case) will be calculated. Users are able to tick multiple checkbox in the risk analysis dashboard and multiple combinations of hazard and EaR for each selected dashboard checkbox. Once users click the button 'Compute Risk' in the risk analysis dashboard user interface in Figure 6, all the corresponding risk curve parameters are

simulated using least square method and risk values are computed based on the equation below.

$$\text{Risk} = \frac{1}{T_1} * S_1 + \left(\frac{1}{T_2} - \frac{1}{T_1}\right) * \frac{S_1+S_2}{2} + \left(\frac{1}{T_3} - \frac{1}{T_2}\right) * \frac{S_2+S_3}{2} + \left(\frac{1}{T_4} - \frac{1}{T_3}\right) * \frac{S_3+S_4}{2} + \left(\frac{1}{T_5} - \frac{1}{T_4}\right) * \frac{S_4+S_5}{2}$$

Where T1, T2 etc. are the return periods used, and S1 , S2 etc. are the losses. For example, take the data listed in Table 1 as input data, the annualize risk value is 18.9 euro.

Table 1: Dummy data for demonstration of computing risk values

T (yr)	S (€)
250	1000
100	500
50	200
25	100
10	10
5	2

$$\text{Risk} = \frac{1}{250} * 1000 + \left(\frac{1}{100} - \frac{1}{250}\right) * \frac{1000+500}{2} + \left(\frac{1}{50} - \frac{1}{100}\right) * \frac{500+200}{2} + \left(\frac{1}{25} - \frac{1}{50}\right) * \frac{200+100}{2} + \left(\frac{1}{5} - \frac{1}{10}\right) * \frac{10+2}{2} = 18.9\text{€ per year}$$

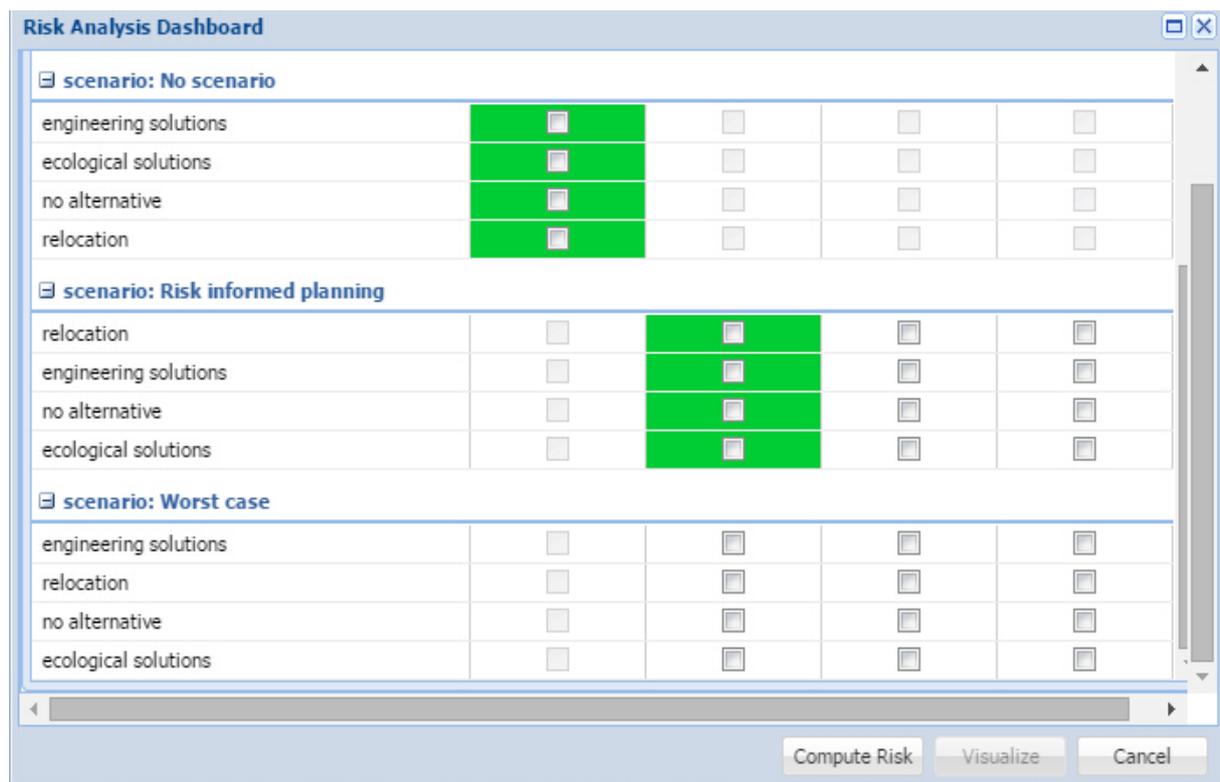


Figure 6: Risk analysis dashboard user interface

Users are able to visualize risk values and curves in the whole study area by clicking the button 'Visualize' in the risk analysis dashboard user interface. A tab is added in the main view in the website as shown in Figure 7. The tab lists the study area, project and the risk

analysis name users defined, as well as a grid containing the risk values. For example, the first record in Figure 7 shows that the economic risk value of all EaR under all Hazards in current situation (no scenario, no alternative and current year 2014) in the whole study area is 652049.64€. If users tick the checkbox, the risk curve is depicted below the grid along with the loss values in different return periods. The risk values and curves for each unit in the mapping unit layer could be visualized in another component 'Visualization' within the system.

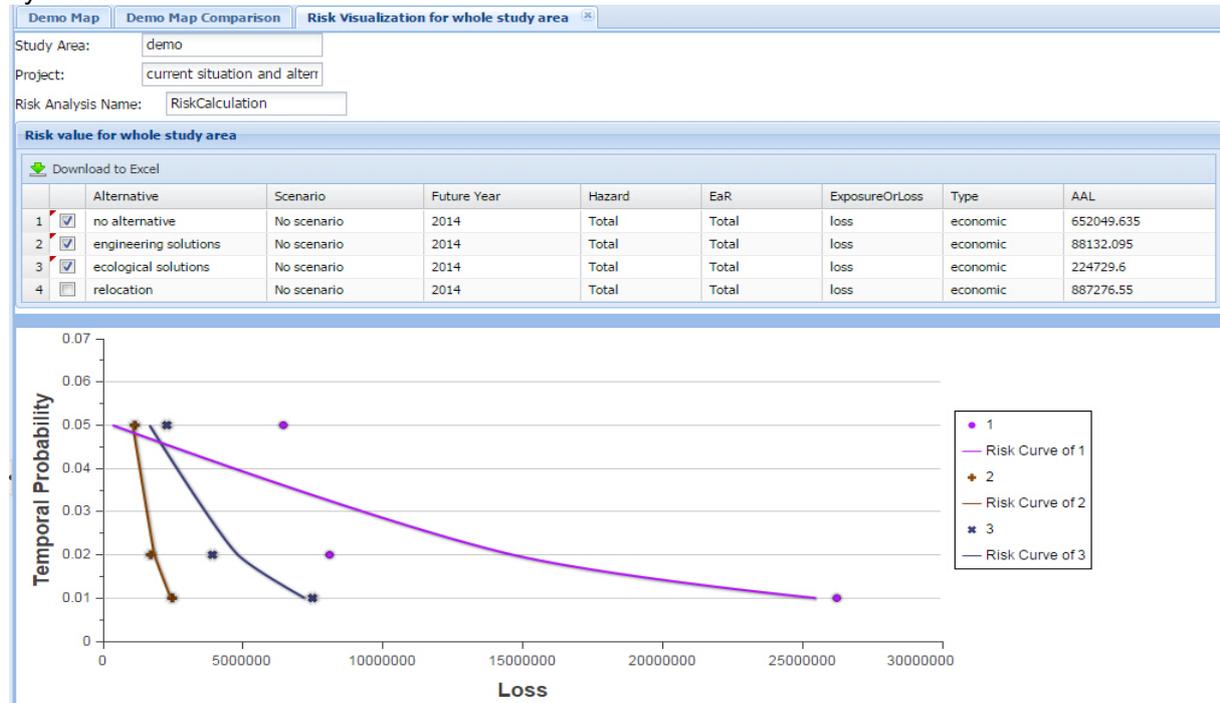


Figure 7: Example of risk analysis results

CONCLUSION

The risk assessment component enables users to compute single hazard and multiple hazards risk. This component plays an important role within the system, since its outputs are the basis for decision making module within the system. The implementation of this module will contribute to the development of open source web-based modules for multi-hazard risk assessment in the future.

ACKNOWLEDGEMENTS

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