



**An interactive
web-GIS tool for risk
analysis: a case
study in the Fella
River Basin, Italy**

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An interactive web-GIS tool for risk analysis: a case study in the Fella River Basin, Italy

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Abstract

This paper presents a prototype of an interactive web-GIS tool for risk analysis of natural hazards, in particular for floods and landslides, based on open-source geospatial software and technologies. The aim of the presented tool is to assist the experts (risk managers) in analysing the impacts and consequences of a certain hazard event in a considered region, providing an essential input to the decision making process in the selection of risk management strategies by responsible authorities and decision makers. This tool is based on the Boundless (OpenGeo Suite) framework and its client side environment for prototype development, and it is one of the main modules of a web-based collaborative decision support platform in risk management. Within this platform, the users can import necessary maps and information to analyse areas at risk. Based on provided information and parameters, loss scenarios (amount of damages and number of fatalities) of a hazard event are generated on-the-fly and visualized interactively within the web-GIS interface of the platform. The annualized risk is calculated based on the combination of resultant loss scenarios with different return periods of the hazard event. The application of this developed prototype is demonstrated using a regional data set from one of the case study sites, Fella River of North Eastern Italy, of the Marie Curie ITN CHANGES project.

1 Introduction

During recent years, natural hazard and risk assessment has become a major topic of interest among natural and social scientists, engineering professionals, endangered communities and local administrations in many areas of the world (Aleotti and Chowdhury, 1999). At the same time, hazardous processes in mountainous environments, such as landslides, debris flows and floods have also increased in terms of frequency, magnitude and impact, as a result of climate change combined with continuously growing settlement areas (Sterlacchini et al., 2014). An increase in occurrences of such

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hazard events can be expected in the future due to the extreme rainfall events associated with climate change. Landslides happen in different geological and environmental settings in Europe each year (EM-DAT, 2003; EEA, 2010) and are mostly triggered by intense and long rainfalls (Krejčí et al., 2002; Zêzere et al., 2005; Guzzetti et al., 2007; Brunetti et al., 2010), though other factors, such as rapid snowmelt, earthquakes, and human activities such as deforestation and constructions in sloping terrains, also contribute to the occurrences of these events. Natural processes alone present no risk unless they threaten some elements-at-risk (Alexander, 2004). Therefore, it is important to analyse where these hazard events can occur and with which frequency, as well as the elements which are exposed to hazard events and their vulnerability (i.e. degree of loss), leading to the identification of areas at risk. Einstein (1988, p. 1076) defined risk as “the multiplication of hazard and potential worth of loss since the same hazard can lead to entirely different consequences depending on the use of the affected terrain risk”.

Risk assessment and management includes the estimation of the level of risk, followed by an evaluation whether this level of risk is acceptable and if this is not the case, the adaptation of appropriate measures need to be taken for risk mitigation (Aleotti and Chowdhury, 1999; Dai et al., 2002; Crosta et al., 2005; Sassa and Wang, 2005; Fell et al., 2008). For management purposes, risk assessment should be able to support the decision-making process in order to contribute to the effectiveness of risk management (Carreño et al., 2007). Therefore, a comprehensive and accurate risk assessment needs to be carried out, realizing its important role in the risk management framework. There are several assessment methods which can be applied depending on the study scale, availability of data and aims of the analysis (Lee and Jones, 2004; Glade et al., 2005; van Westen et al., 2006; Corominas et al., 2014), which can be grouped into qualitative, semi-quantitative and quantitative methods. The quantitative assessment of hazard and risk has become an essential practice in risk management (Fell and Hartford, 1997) and this approach should quantify the expected losses as the product of the probability for a given intensity, costs of exposed elements-at-risk



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or number of exposed people, and their associated vulnerability (Uzielli et al., 2008). However, risk assessments are often complex in nature and many aspects of the risk cannot be fully quantified (Jaboyedoff et al., 2014) due to the lack of data, scale of study or other socio-economic aspects of study area. Therefore, if insufficient data is available for a quantitative assessment, qualitative approaches are adopted, which are often based on spatial multi-criteria evaluation (SMCE) methods (Castellanos Abella and van Westen, 2007; Raaijmakers et al., 2008) and risk matrix approaches (Pine, 2008; FEMA, 2001) for risk prioritization, ranking and evaluation. In this paper, the scope is limited to quantitative risk estimation (analysis).

Geographical Information Systems (GIS) play a central role in natural hazards risk assessment referenced to a geographical location (Peggion et al., 2008). Nowadays, with the support of advanced internet developments, open source data, software and technologies, it became much easier to exchange and analyse spatial information on the web through web-GIS based applications. Web-GIS is the combination of web technologies and GIS for data handling and analysis of spatial data on the web, simplifying exchange of data and providing structural information to users without needing to install additional standalone software (Yang et al., 2005). In recent years, a number of studies have been conducted on the design and development of web-GIS applications for different purposes in the field of natural hazards and risk management (Lan et al., 2009; Frigerio and van Westen, 2010; Pessina and Meroni, 2009; Furdu et al., 2013; Open-Quake, 2015). However, most web platforms have focused mainly on risk visualization and dissemination of information (Müller et al., 2006; Salvati et al., 2009; Giuliani and Peduzzi, 2011; Frigerio et al., 2014) while risk assessment applications still remain as desktop-based applications such as CAPRA-GIS (a modular and free GIS for probabilistic risk analysis of natural hazards) or the InaSAFE (a free and open source plugin to calculate impact scenarios for natural hazards) of Quantum GIS (QGIS) software. Further research needs to be done on the development of interactive risk analysis and management tools, taking the benefits of advanced web and web-GIS technologies to achieve a centralized integrated framework. A good example of such developments for



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5 earthquake risk assessment was realized based on Geonode (an open source platform for the creation, sharing, and collaborative use of geospatial data) and OpenQuake engine (an open source software for seismic risk assessment) by the Global Earthquake Model (GEM) foundation. Moreover, with the use of open data, it has become possible to perform rapid damage assessment using OpenStreetsMap (Westrope et al., 2014) and its base data can be extracted (Schelhorn et al., 2014) and integrated in web-GIS applications for analysis.

10 The aim of the paper is to contribute to the practitioners in the open-source and research community through the development of an interactive, open-source web-GIS based risk analysis tool for natural hazards, such as floods and landslides. Section 2 presents the background methodology, workflow and architecture used for the development of the prototype together with the data model design and calculation procedures of the prototype risk tool. In Sect. 3, we demonstrate the components of the prototype using a regional data set from the Fella River Basin area in Italy, where flash floods, river floods and debris flows are frequent and cause severe consequences. Finally, a discussion of limitations and potential improvements of the presented risk analysis tool is reported.

2 Background framework and methods

20 An overview diagram of the prototype platform is presented in Fig. 1, where the risk analysis tool is one of the main modules. The data management module acts as an essential input to the risk analysis module in order to provide the necessary data (i.e. hazards, elements-at-risk and vulnerability information) for the calculation of loss and risk scenarios. The purpose of loss component is to quantify the probability of losses either in monetary values or fatalities caused by a hazard event in a specific area for a certain time period. The risk component produces a risk curve which shows the relationship between frequency and its associated losses of hazard events. When the resultant risk level is not acceptable, the results of risk analysis are then applied in the

with or without class (types) information about a specific category of elements-at-risk. An example of vulnerability curve is illustrated by the cumulative distribution function (CDF) in Fig. 2, with its defining equation (Kotz and van Drop, 2004; Haimes, 2009):

$$\text{CDF} = F(x) = \begin{cases} 0, & x < a \\ \frac{(x-a)^2}{(b-a)(c-a)}, & a \leq x \leq c \\ 1 - \frac{(b-x)^2}{(b-a)(b-c)}, & c < x \leq b \\ 1, & x > b \end{cases} \quad (2)$$

5 where x is a given intensity value, a is the lowest intensity value, b is the highest intensity value, and c is a varying value between a and b . The resulting loss scenarios (either fatalities or damages) of a specific hazard event with different return periods are then combined to compute the annualized “risk” total (R) per year. It can be represented in the form of a risk curve (van Westen et al., 2010), and in this paper, the staircase-
 10 shape curve is applied for the calculation of total risk, as illustrated in Fig. 3, showing the contribution of the selected scenarios to the annualized total risk (R). Therefore, the resulting annualized risk here represents the area below the staircase rather than the area under the fitted (black) curve of the combination of frequency and loss of all scenarios:

$$15 \quad R = \sum_j R_j \quad (3)$$

$$R_j = f_j \times A_j \quad (4)$$

$$f_j = f(A_j) = \frac{1}{T_j} - \frac{1}{T_{j+1}} \quad (5)$$

where R_j is the annual risk of the scenario j , f_j is the frequency of the scenario j and A_j is the loss of the scenario j .

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Finally, in a last step, if no vulnerability information is given, a vulnerability value of 1 (complete damage) is assumed. If vulnerability data is available, the user can either select the option “Data Ranges” or “Function” according to the data structure, which can be uploaded or created in the data management module. The user then matches the vulnerability information (columns) with information given (column attributes) for the selected elements-at-risk. Finally, the loss scenario is calculated on the fly based on these input data. The resulting calculated loss scenario can be visualized interactively in the web-GIS interface of the platform. This process is repeated for all available hazard scenarios with different return periods and for all elements-at-risk. The batch processing of all loss combinations of hazards with different return periods and elements-at-risk scenarios is possible to include in future versions of the platform.

The resulting loss scenarios with different return periods are then combined to produce an annualized risk based on the staircase approach as mentioned above in Eq. (3) and Fig. 3. At least three different loss scenarios of the same hazard event with different return periods are required to calculate the annualized risk and visualize the risk curve within the platform. This process starts with the summation (aggregation) of the losses (A_j) for each loss scenario of a certain elements-at-risk. Then, each loss total is multiplied with the respective frequency values ($f_j = 1/T_j - 1/T_{j+1}$) to obtain the annual risk (R_j) for each step of the staircase curve (Fig. 3), and finally, the summation of all steps R_j produces the total annualized risk (R) for the specific hazard event considered. The step-by-step conceptual workflow of this risk calculation component is shown in Fig. 6, and this process is repeated for different types of hazards. In this prototype version, we did not consider whether hazards are dependent or not. Moreover, we only considered calculating the area under the staircase-shaped curve, and therefore, there are possibilities to improve the calculation of the entire area under the curve. In addition, the calculation was carried out for the whole study area rather than per administrative units.



2.3 Background architecture

The Boundless (formerly OpenGeo) framework was used to develop this prototype version of the platform. It offers a complete open-source geospatial architecture with modular components (Boundless, 2015). PostGIS database is integrated for data storage of spatial data. GeoServer and GeoWebCache are used for application servers to access and render the data through web map services. GeoExt, ExtJS and OpenLayers (JavaScript libraries) are applied for the user interface framework of the interactive web map application across web-browsers and mobiles. It also provides a client side software development kit (SDK) environment to build JavaScript-based complete customizable web mapping applications. This prototype platform is based on GXP template (a JavaScript SDK) for developing high level GeoExt based applications with OpenLayers 2. The presented risk analysis module and other supporting modules are developed as plugins within the platform. The possibility to develop such customized plugins makes the tools reusable when and where needed, facilitating the implementation phase much faster with integration of available map tools and functionality.

2.3.1 Schema design

A part of the data model of the prototype platform, focusing mainly on the presented risk analysis module, is illustrated in Fig. 7 together with its supporting data management module. The input information related to the hazards, elements-at-risk maps and vulnerability information are recorded in the tables of hazards, elements-at-risk and vulnerability, respectively. The hazards table records the information related to each hazard map such as type (e.g. flood), return periods (e.g. 100 years), name of the hazard map, etc. Similar type of information is also recorded in the elements-at-risk table for all elements-at-risk layers (e.g. replacement value, type, and population information). In the vulnerability table, information related to vulnerability data or function curves is recorded. In all cases, the mapping index attribute serves as an important look-up index to link each record in parent tables (e.g. elements-at-risk) with its corre-

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sponding child tables (e.g. Fella buildings) in the database and layers in the Geoserver. Like the other tables, the information related to each loss scenario such as name, description and category of the scenario is recorded in the loss scenario table, and this table is linked to the other three tables (hazards, elements-at-risk and vulnerability) in order to retrieve the input information which is necessary for the calculation of a specific loss scenario. For the follow-up calculation of the annualized total risk of a certain hazard with different return periods, this loss scenario table is linked with annualized risk table through a loss-risk table since a total risk scenario could include at least three or more loss scenarios with different return periods. The annualized risk table contains the information related to the calculated annualized risk total such as name, description and total amount (per year). The mapping index links to its associated child table which stores the summary information of loss and annualized risk with return period information of each loss scenario of the considered hazard event.

2.3.2 Processing steps for calculating losses and risk

For the loss calculation component, the processing is done mainly within the PostGIS database and the results of each calculated scenario are published to Geoserver for visualization purposes within the web-GIS interface through Web Map Services (WMS) and Web Feature Services (WFS) of OGC (Open Geospatial Consortium) standards. In the Data Management module, the map layers (hazard maps – in raster format and elements-at-risk maps – in vector format) can be imported into the database and Geoserver for processing and visualization. With the use of Geoserver’s import configuration, vector map layers are imported not only to the Geoserver but also directly to the database while raster map layers need to be further imported into the database through *raster2pgsql* tool, a raster loader for raster format data into a PostGIS raster table for processing. The algorithm for the calculation of a loss scenario within the database (in the case of buildings, as elements-at-risk) has the following steps:

1. Create a loss table based on the given input data.



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- a. Perform a spatial intersection (ST_Intersects) operation on the hazard intensity raster map with elements-at-risk map using geometry (spatial) intersection.
 - b. Perform a clip (ST_Clip) operation to crop the intersected raster which are converted into polygons using the ST_DumpAsPolygons operation to obtain raster band pixel values formed by a polygon geometry.
 - c. Perform count, min, max and average operations on pixel values of the clipped polygons to obtain the intensity values of the hazard intensity, grouped and ordered by each affected unique identifier of the objects.
2. Fill in the attribute columns of the loss table (only if vulnerability data is available) to calculate loss estimates.
- a. Extract spatial probability values of each affected object (either from maps or given value).
 - b. Extract vulnerability values of each affected object by mapping in the vulnerability lookup table or calculating using the given vulnerability function.
 - c. Multiply spatial probability, vulnerability value with its corresponding amount value of each affected object.
3. Register the calculated loss scenario record in loss scenario table of Fig. 7.

As a final step, this calculated loss scenario is published to the Geoserver for user visualization in the platform through cURL (client URL) and Geoserver's REST (Representation State Transfer) configuration, which allows to create, retrieve and update information in an XML (EXtensible Markup Language) format, for example, to obtain information on the existing published layers or styles information of layers stored in Geoserver.

After calculating each loss scenario for different return periods of a considered hazard, the algorithm for the total annualized risk is performed as follows:



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1. Create a total risk table that stores the information about a collection of considered loss scenarios (i.e. return period, frequency, number of affected elements-at-risk, loss and annual risk value of a loss scenario).
 - a. Populate the table with records of return period, frequency and its corresponding losses.
 - b. Update the table's risk attribute value to compute the annual risk (the calculation as explained in Sect. 2.2 and Fig. 6).
2. Register the summed annual risk total record in annualized risk table of Fig. 7 along with additional information.
3. Register the relationship record in the loss-risk table of Fig. 7 to link between loss and annual risk scenarios.

3 Demonstration of the prototype

3.1 Case study of Fella River Basin, Italy

The Fella River is a left tributary of the Tagliamento River, the dominant river system in the Friuli-Venezia-Giulia region, North-Eastern Italy (Cattaneo et al., 2006). The study area is 247 km² in size (Fig. 8) and the catchment has an average altitude and mean precipitation of 1140 m a.s.l. and 1920 mm, respectively (Sangati, 2009). The drainage has a torrential regime due to the concentrated rainfall in intense and erosive showers, the steep topography and the lithology consisting for a large part of limestone and dolomite. In addition, the area is seismically active and characterized by a high distribution of landslides (Borga et al., 2007). Extreme precipitation events leading to hydro-meteorological hazards such as flash floods, landslides and debris flows are frequent in the area, resulting in catastrophic consequences and damages to infrastructure worth hundreds of millions of Euros and human casualties (Scolobig et al., 2008).

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In August 2003, a major alluvial event occurred, triggering landslides and debris flows mobilizing about 1 million m³ of debris material and causing a major flood on the whole Fella River basin (Fig. 9). Moreover, shallow and deep seated landslides and flash flooding also occurred in this area (InCREO, 2014). Despite of being scarcely populated, the valley represents an important transportation and communication corridor in the region, with a high interest of local authorities and population in tourism activities. Therefore, an expansion of touristic and recreational areas could result in more elements-at-risk affected and thus an increase in potential risks to hydro-meteorological hazards.

3.2 Fella River dataset

For debris flow hazards, four types of events have been modelled by Hussin et al. (2014b): frequent, minor, moderate and major with related estimated return periods of 1–10, 10–25, 25–100 and 100–500 years, respectively. The modelled impact pressure (in KPa) from debris flows is considered as the intensity parameter for the debris flows. Figure 10 illustrates the major debris flow event of a part of the Fella study area for the return periods of 100–500 years.

The elements-at-risk database contains information about building characteristics such as location, occupancy type, material of construction, number of floors, building's value (minimum and maximum) and number of people occupying the building (during tourist and non-tourist seasons) (Ciurean et al., 2014). An illustration of the building classification based on construction material and numbers of floors in Pontebba commune is given in Fig. 11.

3.3 Uploading of Fella data in the data management module

As a first step to calculate loss and risk scenarios, the input data needs to be imported into the platform through the data management module, i.e. hazard intensity maps, elements-at-risk maps and associated vulnerability information. If available, the spatial

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probability map associated with a certain hazard event can also be uploaded into the system to be included in the calculation. For example, spatial probability of debris flow can be calculated by overlaying the modelled debris flow areas with actual inventories corresponding to each return periods (Hussin et al., 2014b). The users can either upload data in .tiff format for raster images, or zip format with vector shapefiles with their respective associated information. Upon successful upload of maps to the database and Geoserver, the users can visualize, query and style the layers in the web-GIS interface of the platform. Figure 12 demonstrates the import interfaces of the hazard component, as an example. The additional properties of the imported layers are also recorded in the system, such as type and return period (in case of hazards), and the indication of whether the imported map reflects the current situation or a possible future situation after implementing certain alternative scenario of risk reduction measures (for risk reduction module of the platform).

For the vulnerability component, the user can enter data in the form of numerical values (data ranges) or functions to calculate vulnerability curves. The “data ranges” is a discrete range of minimum and maximum degree of loss values associated with the corresponding minimum and maximum intensity of a certain hazard event, and it can be uploaded by the users in .csv, excel and .txt formats (Fig. 13a). The “function” option is used to upload continuous Cumulative Distribution Function (CDF) together with their specific parameter values, as defined by the users (Fig. 13b). The CDF must fulfil two mathematical requirements: (a) the depending variable, i.e. degree of loss should be confined by the [0–1] interval, and (b) increase steady and monotonic with the interval of the explaining variable, i.e. intensity (Papathoma-Köhle et al., 2012). Such examples of probability functions are the Weibull, Frechet, Log-Logistic, Triangular, Beta, etc. The visualization of vulnerability curves obtained by using both options is demonstrated in Fig. 14a and b, where the average curves obtained from a set of data ranges, and a generic CDF is illustrated respectively.

3.4 Risk analysis module

Each loss scenario is then calculated in the Loss Calculation component of the Risk Analysis module using the available maps and information in the system. As explained in Sect. 2.2, the loss component is composed of three main parts: hazards, elements-at-risk and vulnerability information for calculation of a new loss scenario. The users can first select a “hazard” map amongst the existing ones depending on the type (i.e. either debris flows or floods) and its corresponding spatial probability data either in the form of map or input value in the range of 0 to 1, as shown in the user interface of Fig. 15a. For the “elements-at-risk” part, the same concept applies allowing the users to select an existing map (e.g. buildings) as demonstrated in Fig. 15b as well as to enter additional parameters such as amount (e.g. building value) or different class information (e.g. material type) of the selected elements-at-risk layer. Only the number of affected elements-at-risk can be calculated if no monetary information of the elements-at-risk is given.

In the “vulnerability” part (Fig. 16), the user can indicate whether vulnerability information is available or not. In the case of no information, we assume that the affected elements will be totally destroyed (i.e. vulnerability value equals 1) regardless of hazard intensity. If not, the user can select the available vulnerability information based on its data type (either data ranges or function) and then, importantly, match the vulnerability data with the classes of objects (e.g. material types) accordingly, in order to retrieve the corresponding vulnerability value of a certain intensity on each affected object.

Based on these three types of input information, a new loss scenario is calculated according to the first algorithm described in Sect. 2.3.2. Thereafter, the user can visualize each calculated loss scenario (Fig. 17) where the economic loss (damage) of each affected building by the debris flow hazard can be seen in the pop-up of the map interface. The additional information used to calculate the loss are also presented such as minimum, maximum and average intensity values, vulnerability value based on the building’s material type, spatial probability and monetary values of the building.

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This loss calculation process is repeated for all return periods of a given hazard (in this case, debris flows). After that, these loss scenarios with different return periods of the debris flow event are then combined to calculate the annualized risk (Fig. 18a and b), as mentioned in Sect. 2.3.2. At least three or more loss scenarios with different return periods are required to perform the calculation process of the risk component of this module. The visualization of minimum (Fig. 19a) and maximum (Fig. 19b) risk curves for debris flow events in Fella River study area is demonstrated, along with affected number of buildings and their corresponding losses for each return period of the calculated scenarios.

According to the calculation results, Fig. 19 shows that high return period events (i.e. low frequency events) caused higher losses compared to the low return period events (i.e. high frequency events). For the maximum intensity scenarios of debris flow, the economic losses of the major event reached EUR 15 million (703 houses were affected) while the most frequent event was only EUR 30 thousand (7 houses were affected). The variation in risk estimation can be indicated with minimum and maximum values of total economic losses, for example, in case of major debris flow event, the difference ranges from EUR 3.7 to 15 million. The total annualized risk for debris flow is estimated between approximately EUR 0.026 and 0.4 million (for minimum and maximum scenarios, respectively).

For the same study area, risk assessment has been carried out by Chen et al. (2014) in which a multi-hazard quantitative risk assessment model was developed using historical hazard inventory and GIS technology for risk curves generation and annualized risk calculation. The results of the web-GIS risk analysis tool were compared with the ones produced by Chen et al. (2014). For number of affected buildings, the difference varied from 0 to 100 with an increase in return periods of the events. Fewer buildings were affected as a result of calculations in the web-GIS tool with a difference of 4–10 buildings for minor events, 38–40 buildings for moderate events and 90–100 buildings for major events, while there was no difference for frequent events. Within the web-GIS tool, 5 m × 5 m cell sizes of the debris flow raster maps (with 100 m × 100 m tile sizes) were



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used for calculation within PostGIS database. This cell grid size (5 m × 5 m) was chosen since it gives the better approximate results when compared to Chen et al. (2014), according to the test results obtained by using different cell size raster maps. If a building was touched to multiple pixels of the debris flow raster map, the maximum intensity value of the intersecting pixels was used to retrieve the vulnerability value for loss calculation. A spatial probability value of 1 was applied in the loss calculation for the underestimated (modelled) debris flow maps. Due to discrepancies in raster cell size and spatial probability values, the calculated loss values showed a difference of about EUR 7 million for major events while comparable results were achieved for moderate, minor and frequent events.

4 Discussion and conclusion

This paper presented the design and development of a web-based risk analysis tool which aims to assist in analysing the impacts of flood and landslide events on the society and people, with the demonstration of the prototype using a dataset from Fella River Basin located in North-Eastern Italy (one of the case study areas of the CHANGES project), where frequent floods and landslides occurred with severe consequences for the infrastructure and mountainous community in the region. The presented tool is developed as a module of a prototype decision support platform so that the risk managers can not only analyse areas at risk but also formulate and compare different reduction measures under a web-based collaborative decision making framework with involvement of various stakeholders from different institutions and organizations, enabling a better integrated and transparent decision making approach in risk management. Moreover, this risk analysis tool has been developed based on the feedback of local stakeholders during a workshop organized in September 2014, in Malborghetto–Valbruna municipality located in Fella River Basin, during the dissemination phase of the collaborative decision making module. During this workshop, the stakeholders indicated their strong interest in the potential development of a spatial query based risk



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analysis tool along with a cost-benefit analysis tool for comparison of different risk reduction measures in the area. As a first step, this prototype scenario-based risk analysis module was developed, and as stakeholders suggested, the possibility of integrating a spatial-query based tool could further facilitate the risk analysis process in a much more interactive, query based environment (for example, drawing a polygon query for risk calculation in the web-GIS interface of the platform for a certain area of interests).

Considering that this prototype is in the development phase but represents an essential step towards a more complex risk analysis platform, further improvements on the proposed risk analysis tool can be identified. For example, the vulnerability component could be advanced with the integration of additional vulnerability curves for specific hazards and elements-at-risk types. For the loss component, at its current state, loss scenarios are calculated one-by-one based on input parameters, and therefore, the manual input iteration time of the same process could be reduced with the integration of a batch processing mode with improved processing speed of scenarios. Moreover, qualitative hazard intensity layers in vector format could be further integrated for the calculation. For the risk component, more accurate ways of calculating the total annualized risk under the area of risk curves (i.e. over the combination of loss scenarios with frequency) could be explored and visualization of risk curves can be improved considering different hazards for multi-hazards risk assessment. In this study, all input data required was available and easily imported into the platform. However, availability of hazard intensity (raster) maps and elements-at-risk information can be rather limited for such kind of full quantitative risk analysis, especially in developing countries. Therefore, other approaches dealing with lack of data should also be further integrated within the platform, for example, qualitative impact-probability matrix to assess and compare different situations for affected elements-at-risk at object level based on expert and local knowledge of the territory. Data scarcity can also be overcome through simulation based on values distribution for missing variables and/or adding variables to the existing data, and this would lead to obtaining exceedance curves by running several and random simulations.



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This prototype tool was developed based on Boundless architecture and its client side environment due to its flexible and extensible open-source components, allowing to implement a faster prototyping of the tool. Regarding technical improvements of the tool, the loss scenarios were generated in the spatial database hosted on the server side of the web application. Therefore, raster and vector layers to perform necessary spatial operations are needed to be imported into the database and published on Geoserver for visualization purposes in the web-GIS interface. If the calculation processing of loss scenarios could be directly carried out based on Web Processing Services (WPS) and Geoserver, the importation and publishing procedure to the database as well as to Geoserver could be minimized. Moreover, moving forward to implementing WPS for loss and risk calculation could assist in particular for recalculation of loss and risk scenarios dynamically for the considered risk reduction measures, at least for preliminary risk calculations without needing the users again to re-upload the new updated hazard (raster) maps. Therefore, it would greatly simplify and reduce the complexity of the steps used to recalculate risk taking into account the reduction measures required for collaborative decision making module of the platform. Besides, the risk calculation could benefit from the use of remote data sources from other available web map servers and services provided by responsible organizations of the study area.

To conclude, regardless of some limitations of the presented approach, the prototype tool was achieved as an initial outcome of a prototype decision support platform and its possible application was demonstrated to the stakeholders and tested using a real data set from Fella River Basin study area. Moreover, this prototype is as an initial step towards a more complex system as it plays an important role in obtaining feedback and suggestions from potential stakeholders and users of the application, which leads to a full-scale development of the system based on user-centred designed approach. In addition, rather than being a stand-alone risk analysis tool, this tool has been integrated within a decision support platform. The great benefit lies in achieving an integrated risk management framework which supports the end users and stakeholders in



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better understanding the entire process of risk management starting from identification of areas at risk until the selection of risk management strategies, while providing a centralized, collaborative multi-users platform. Furthermore, this simple risk analysis tool is developed based on a generalized framework with use of open-source software and architecture, and hence, it offers a high degree of replicability and mobility in any other study areas. Unlike desktop-based applications, the end users need not to install any plug-ins or GIS software to analyse the risk and the resultant risk information can be visualized and shared amongst the users for efficient communication and dissemination over the web, benefiting from web-GIS and web technologies. Several functionalities for improvements are planned for future development such as the qualitative impact-probability matrix to analyse risk at object levels, integration of additional vulnerability curves and simulation approaches as well as for working with (semi) qualitative hazard intensity maps. As a final point, we plan to make the developed tool open source and freely accessible at the end of the development in order to contribute towards open source and research community in natural hazards and risk management.

Acknowledgements. The authors would like to express their heartfelt thanks to the local stakeholders (the Civil Protection and Geological Survey of FVG region). We also like to thank our research colleagues from the CHANGES (Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists, Grant Agreement No. 263 953) and IncREO (Increasing Resilience through Earth Observation-IncREO, Grant Agreement No. 312 461) projects for data sharing of their research results and cooperation in this study area. This presented work is carried out under the CHANGES project, a Marie Curie Initial Training Network funded by the European Commission's 7th Framework Program (2011–2014).

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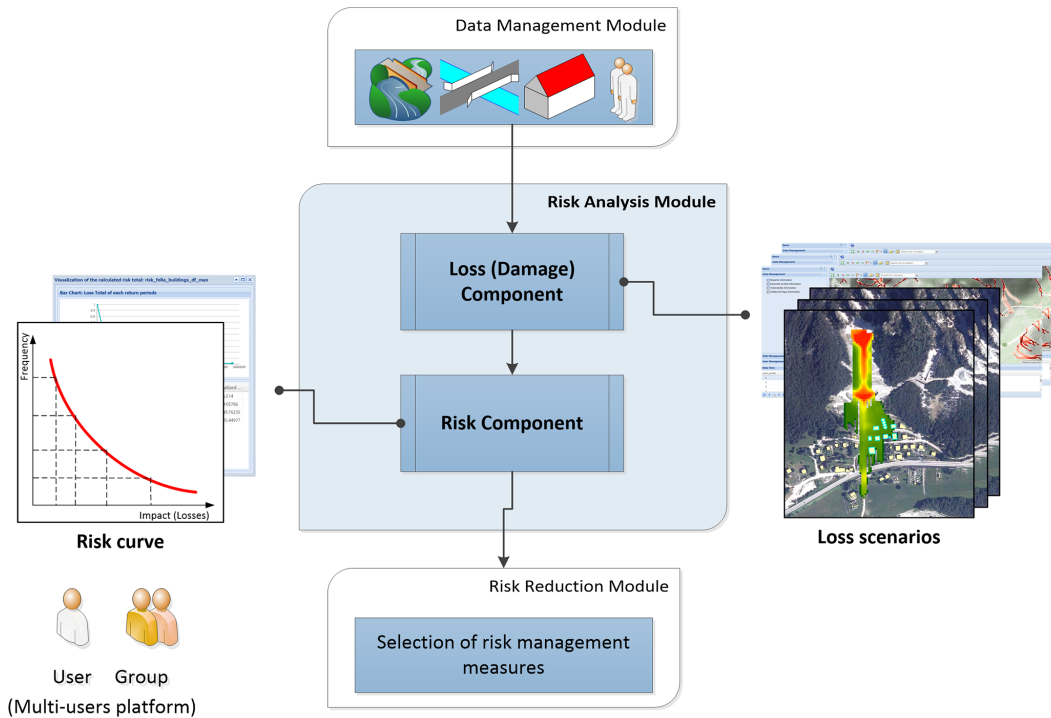


Figure 1. Overview diagram illustrating the main modules of the prototype web-GIS platform.

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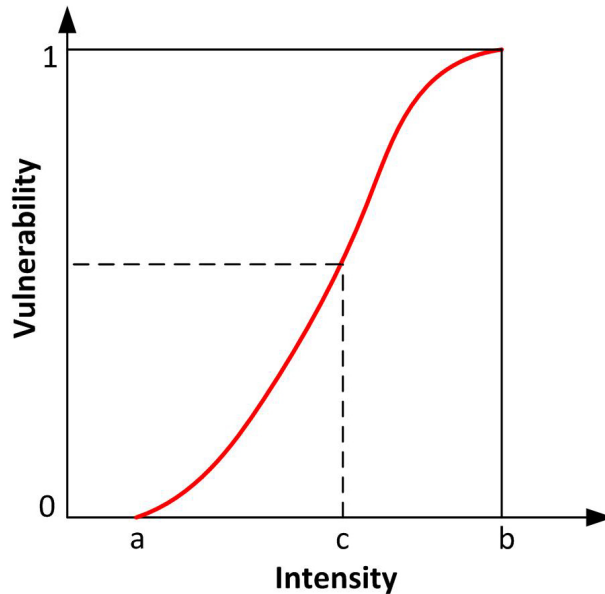


Figure 2. An example illustration of a generic vulnerability curve using a Cumulative Distribution Function (CDF).

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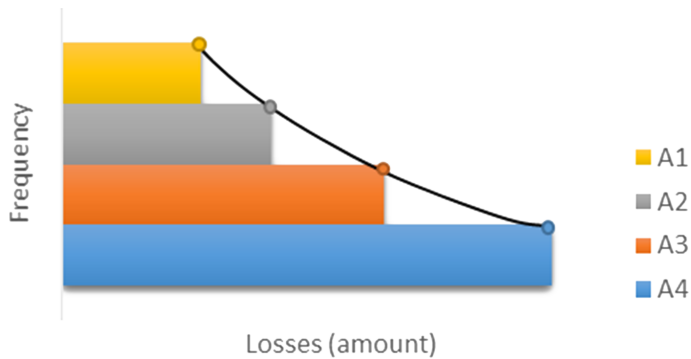


Figure 3. An example of risk curve in the form of staircase. A1 to A4 represents 4 different specific risks of hazard events with a given frequency and the related losses.

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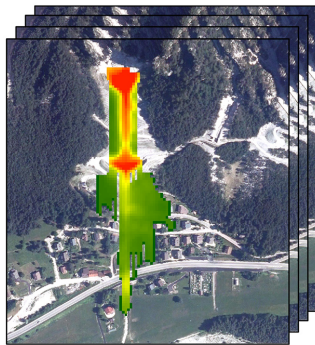
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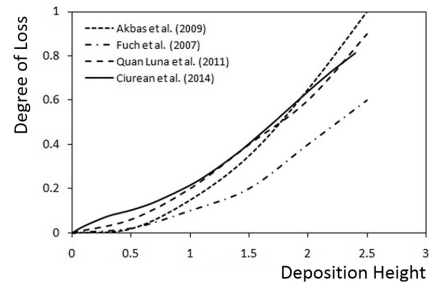




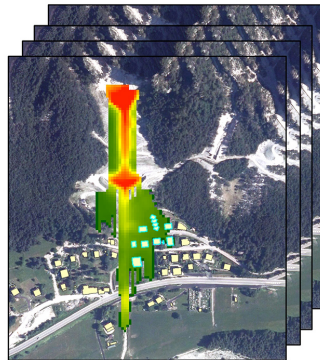
Hazard
(Debris Flow scenarios with different return periods)



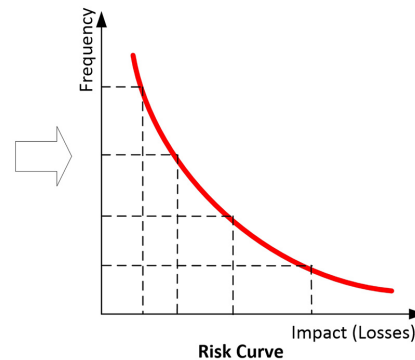
Elements-at-risk
(Buildings)



Vulnerability
(Buildings)



Loss scenarios



Risk Curve

Figure 4. A simple illustration of the generation of loss scenarios and risk curve (adopted from van Westen et al., 2014 with data from Ciurean et al., 2014; Hussin et al., 2014a).

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Step 1: Loss Calculation Component

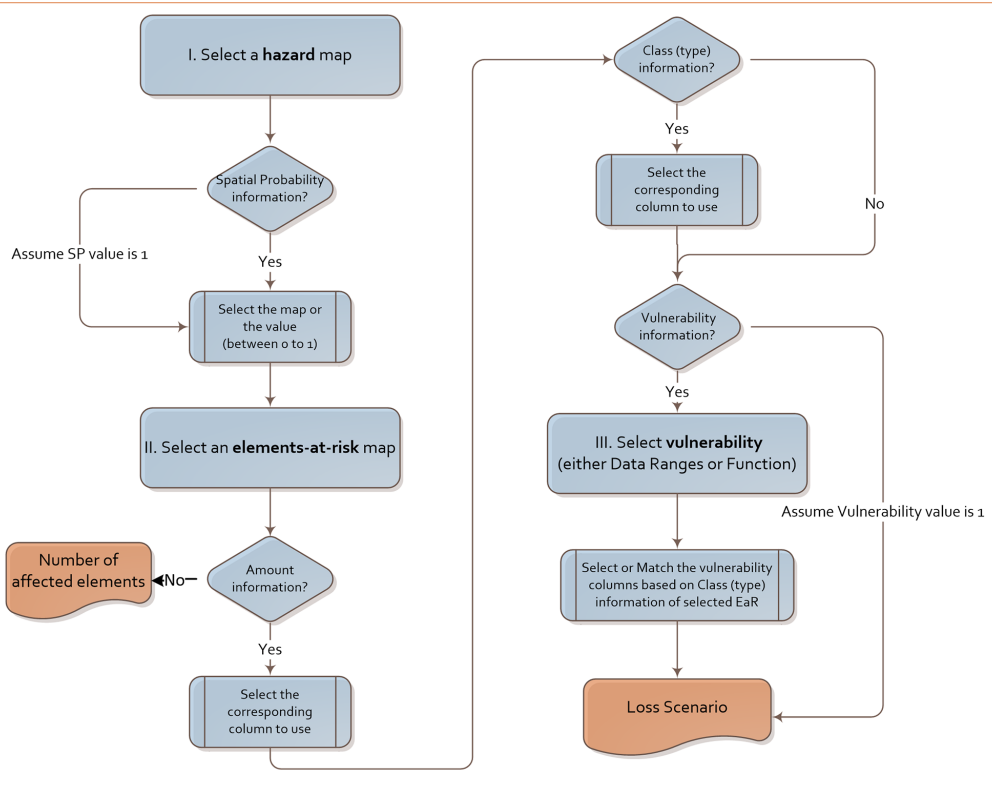


Figure 5. Workflow of the loss calculation component.

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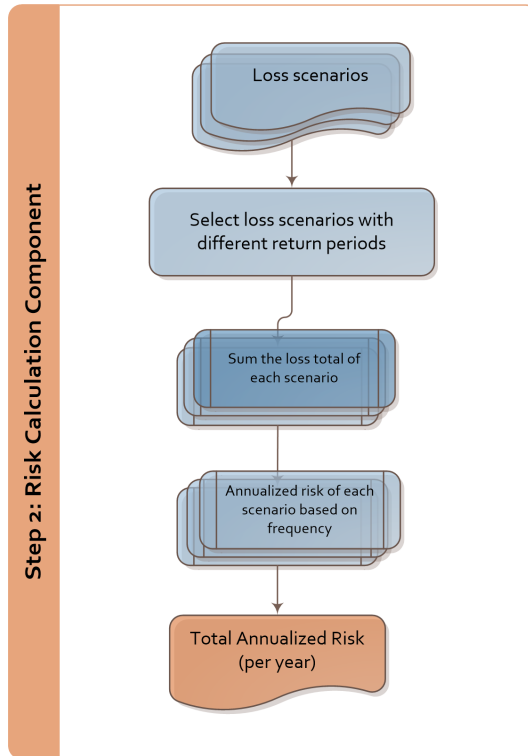


Figure 6. Workflow of the risk calculation component.

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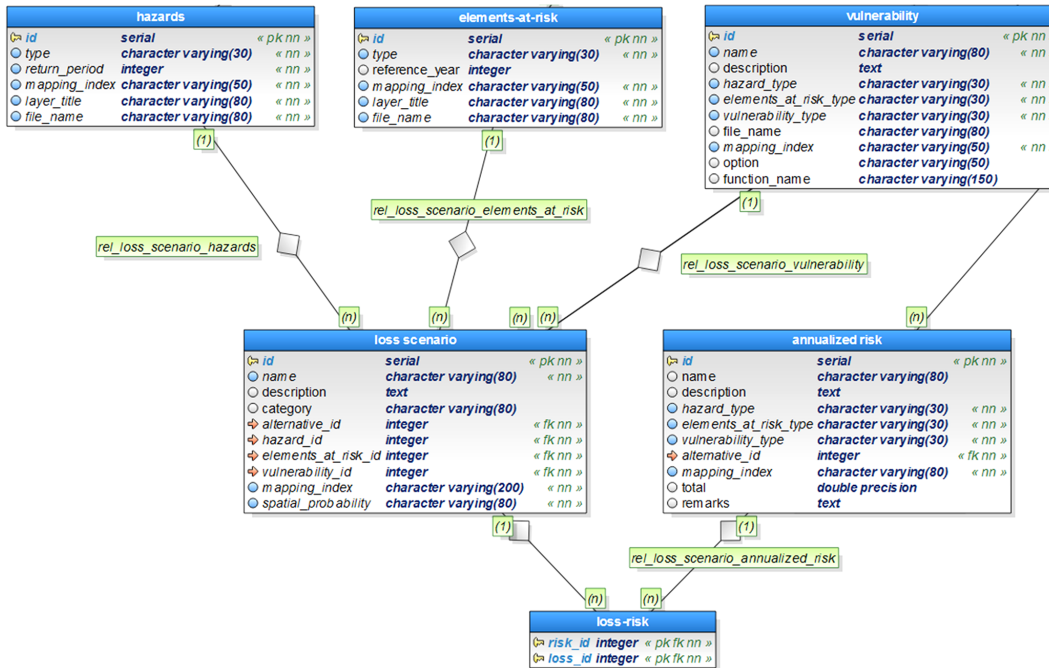


Figure 7. Data model of risk analysis module.

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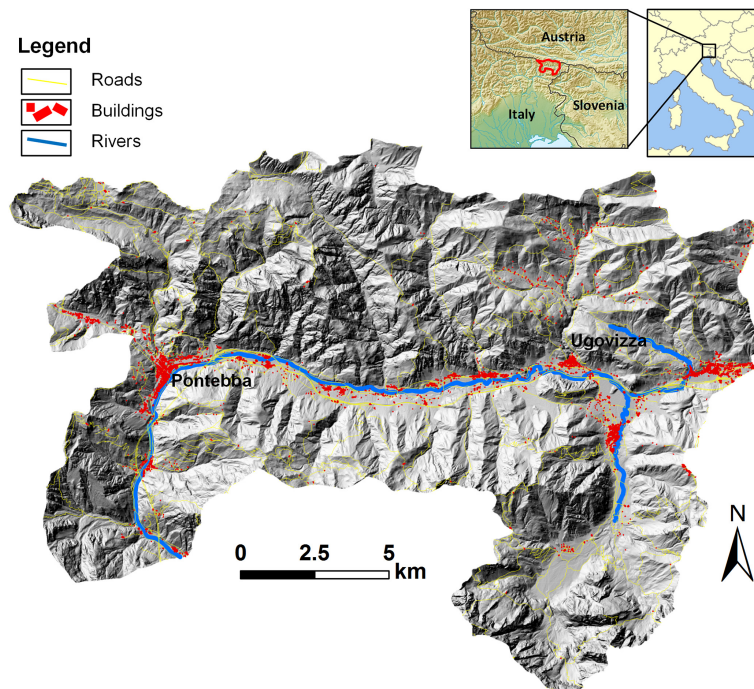


Figure 8. The Fella River study area, Friuli-Venezia-Giulia region, NE Italy (data from Chen et al., 2014; Ciurean et al., 2014; Hussin et al., 2014b).

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Figure 9. Debris flow events in Fella River basin in August 2003 (©Civil Protection of FVG region, Italy).

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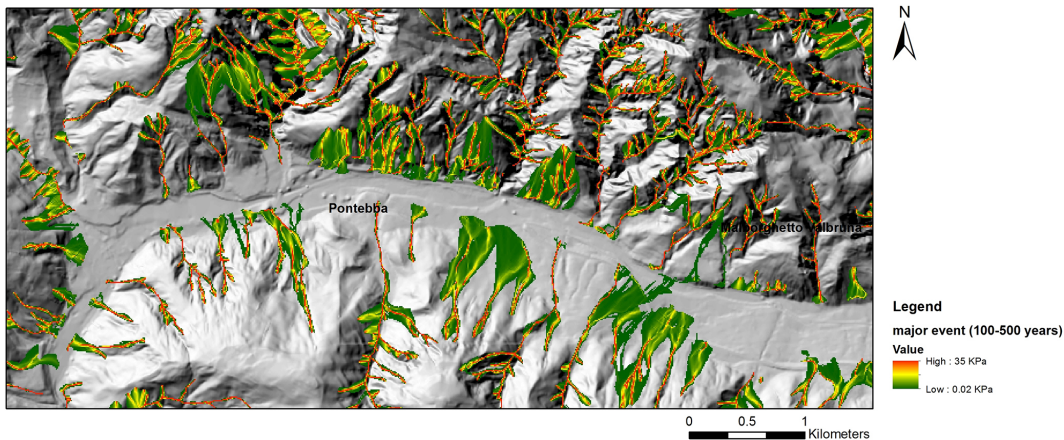


Figure 10. Debris flow (maximum intensity) of major event with return periods of 100–500 years (Hussin et al., 2014b).

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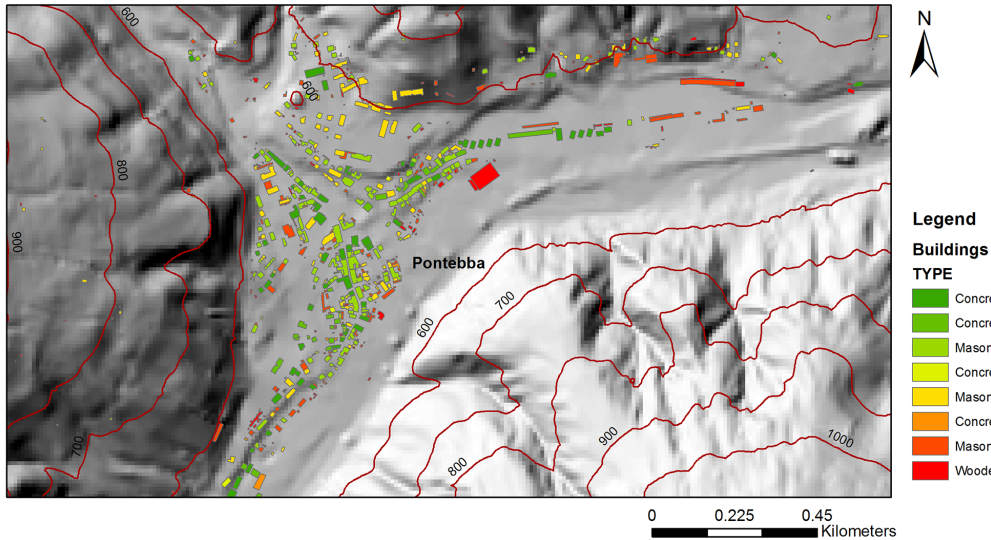


Figure 11. Classified building information in Pontebba commune, Fella River Basin (Ciurean et al., 2014).

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Upload Hazard Map

Title: Layer title

Description: Layer description

Data: Browse for data archive...

Options

Workspace: Default workspace

Store: Default data store

CRS: Coordinate Reference System ID

Properties of the uploaded hazard layer

Type: Type of hazards

Return Period: Return Period

Alternative Name: Select the alternative

Upload Reset

Figure 12. The import interface of hazard component.

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(a) **Define Vulnerability Curve**

Curve Information:

Name:

Description:

Curve belongs to which types of:

Hazard:

Elements at Risk:

Vulnerability:

Alternative:

Curve Definition:

Input Options:

Browse Data:

Figure 13.

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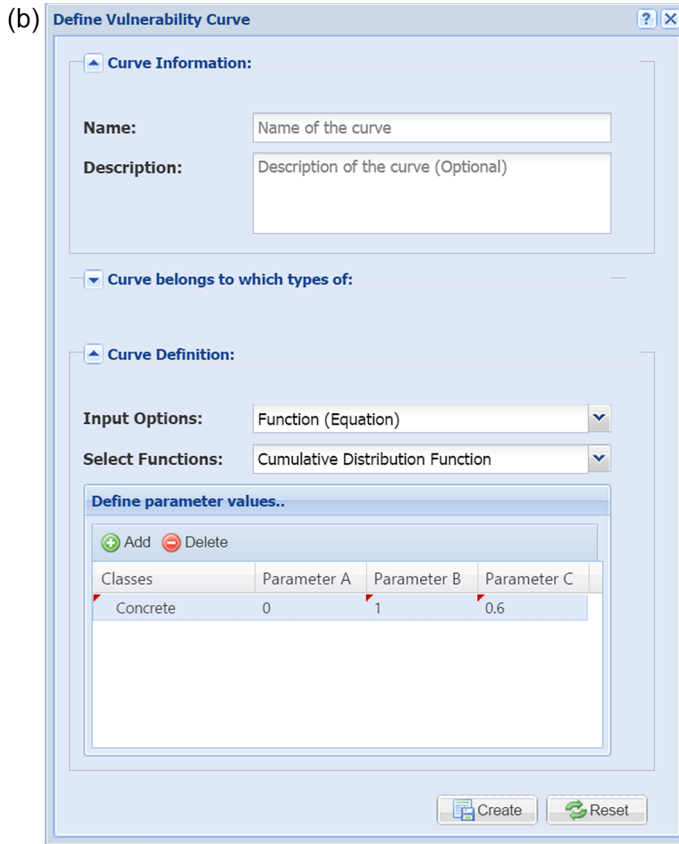


Figure 13. (a) Vulnerability component with “data ranges” option. **(b)** Vulnerability component with “CDF function” option.

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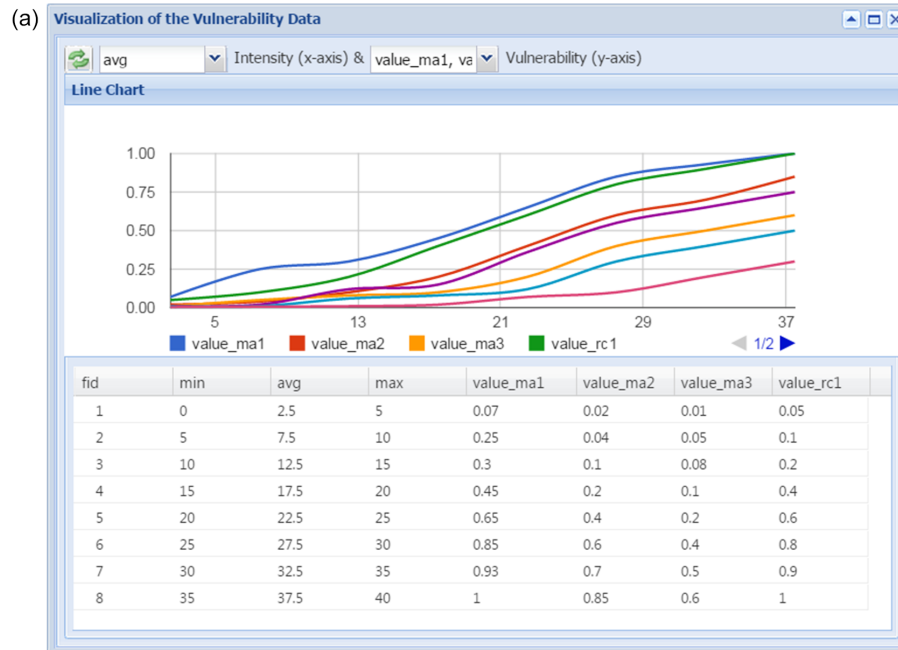


Figure 14.

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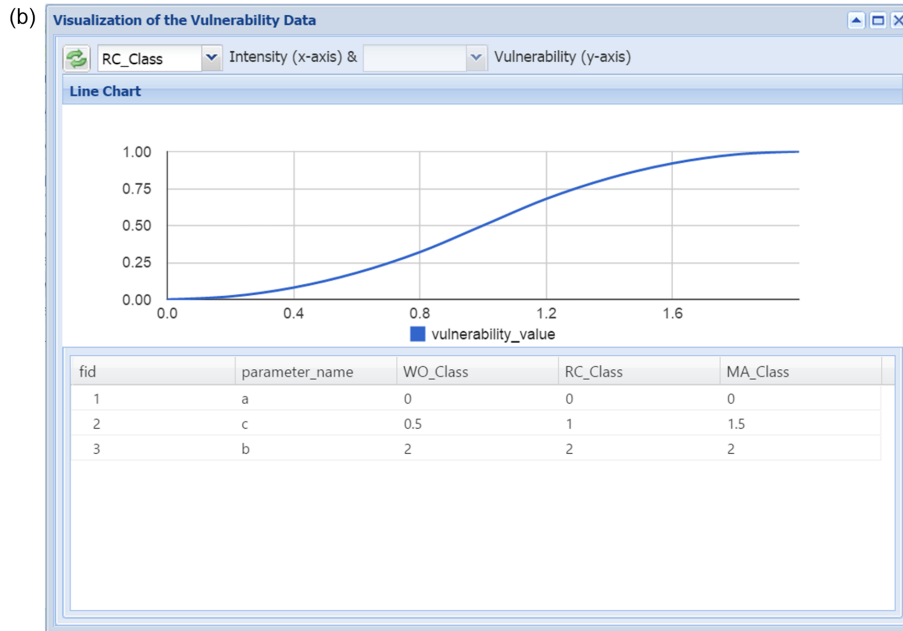


Figure 14. (a) Visualization of the vulnerability curves generated using data ranges. (b) Visualization of the vulnerability curve generated using CDF function.

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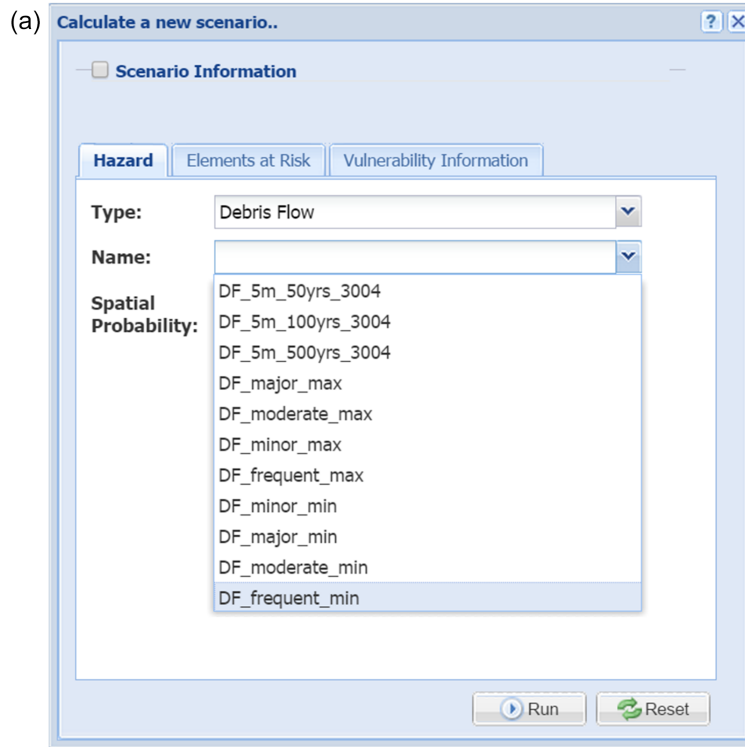


Figure 15.

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(b) Calculate a new scenario..

Scenario Information

Hazard | **Elements at Risk** | Vulnerability Information

Type: Buildings

Name: Buildings_fella

Amount(\$): Yes VALUE_MAX

Classes: Yes

- fid
- the_geom
- BUILDINGS
- USE
- MATERIAL
- NR_FLOORS
- TYPE
- VALUE_MIN
- VALUE_MAX
- PEOPLE_MIN
- PEOPLE_MAX
- COMMUNE
- ADMIN_UNIT

Reset

Figure 15. (a) Selection of hazard input parameters for calculation of a loss scenario. (b) Selection of elements-at-risk input parameters for calculation of a loss scenario.

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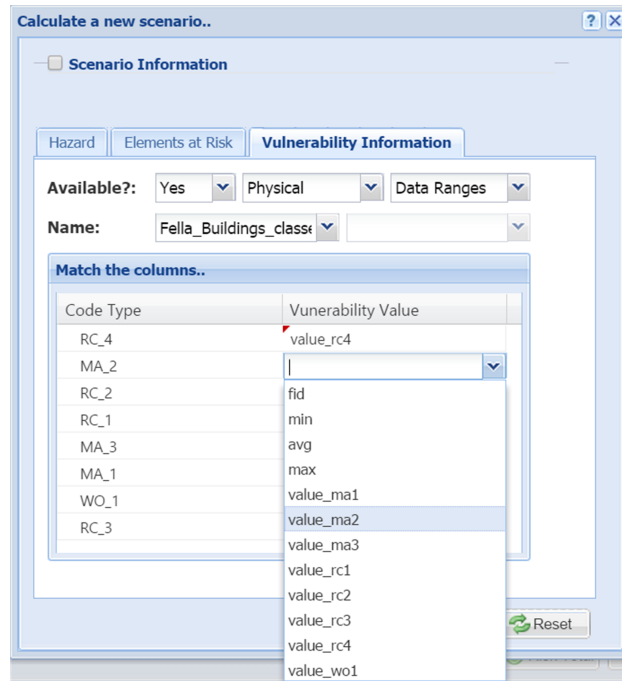


Figure 16. Selection of vulnerability input parameters for calculation of a loss scenario.

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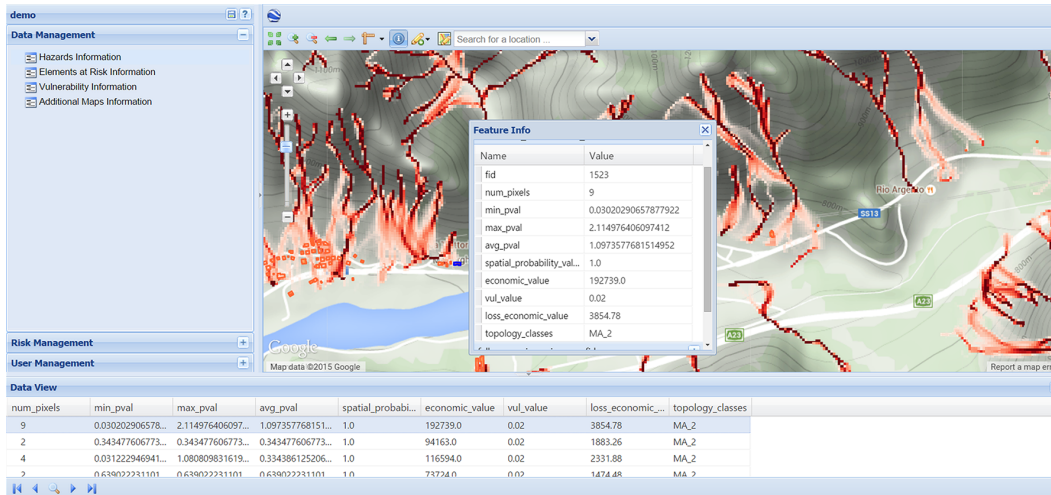


Figure 17. Visualization of the calculated loss scenario.

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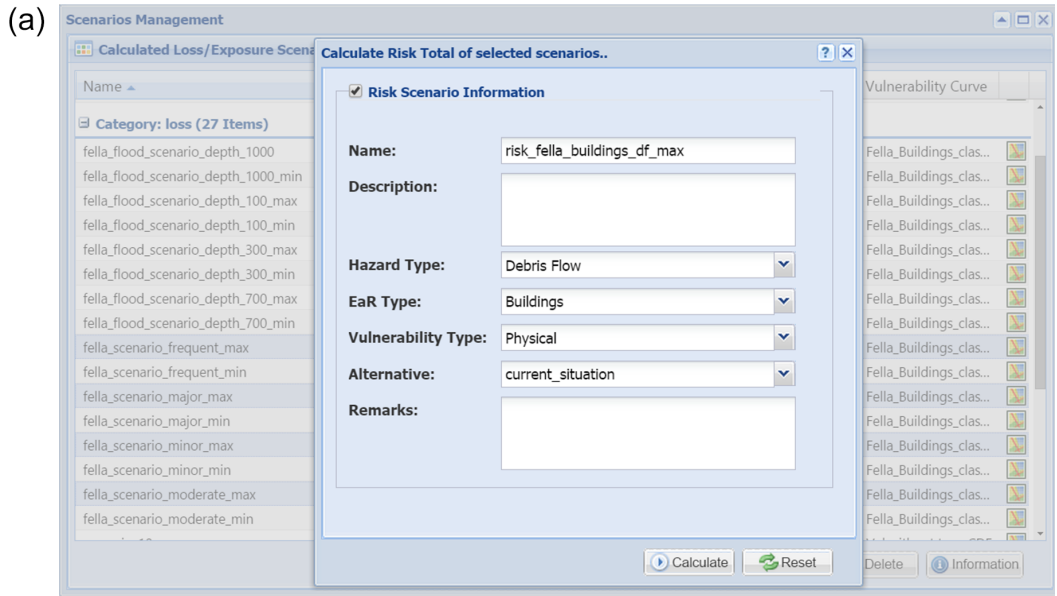


Figure 18.

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(b)

Name	For Alternative	Hazard Ty...	EaR Type	Vulnerability...	Annualize...
For Alternative: current_situation (5 Items)					
risk_cucco	current_situation	Debris Flow	Buildings	Physical	0.40671044...
risk_fella_buildings_df_max	current_situation	Debris Flow	Buildings	Physical	401070.783...
risk_fella_buildings_df_min	current_situation	Debris Flow	Buildings	Physical	26745.07866
risk_fella_buildings_flood_max	current_situation	Floods	Buildings	Physical	94098.4849...
risk_fella_buildings_flood_min	current_situation	Floods	Buildings	Physical	47636.3885...

Figure 18. (a) Selection of loss scenarios with different return periods for calculation of an annualized risk scenario. (b) Visualization of the calculated annualized risk scenarios.

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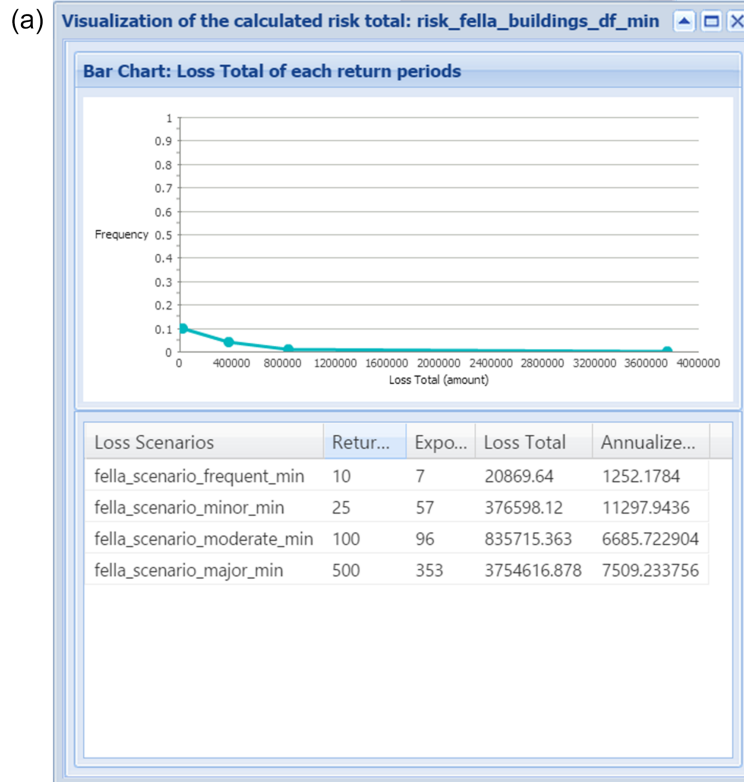


Figure 19.

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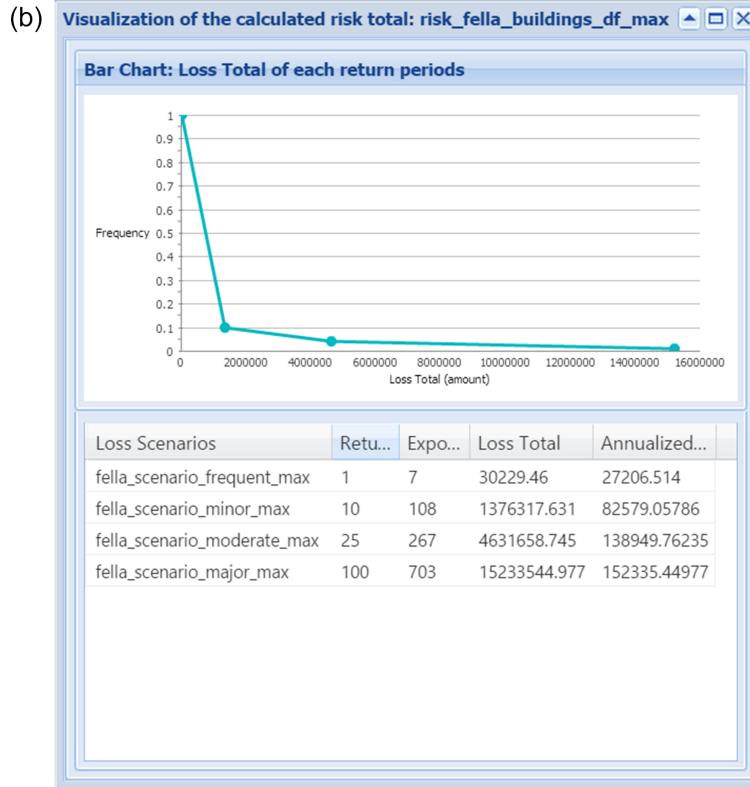


Figure 19. (a) Visualization of the debris flow risk curve (minimum). (b) Visualization of the debris flow risk curve (maximum).

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