BO3

Quantitative vulnerability assessment of buildings to debris-flows in Fella River Basin using run-out modeling and damage data from the 29th of August 2003 event

R. Ciurean[1], L. Chen[2], H. Hussin[2], C. van Westen[2], T. Glade[1], S. Frigerio[3], A. Pasuto[3]

[1] Department of Geography and Regional Research, University of Vienna, Vienna, Austria
[2] Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, Netherlands
[3] CNR-IRPI, National Research Institute for Geo-hydrological Protection, Padova, Italy

Corresponding author details:
R. Ciurean, Department of Geography and Regional Research, University of Vienna, Universitätstrasse 7, 1010, Vienna, Austria, E-mail: roxana.liliana.ciurean@univie.ac.at

Keywords:
Vulnerability, empirical curves, debris flow, run-out modeling, buildings, Fella River, Italy

INTRODUCTION

Extreme rainfall events trigger floods and debris flows with considerable consequences in mountain regions worldwide. The reduction of possible human and material losses is dependent on the assessment of risks as well as design and implementation of effective reduction strategies. These in turn rely not only on the analysis of the magnitude and frequency of the harmful events but also on the comprehensive evaluation of exposed elements and their vulnerability. Vulnerability is defined as the degree of loss to a given element or set of elements at risk resulting from the occurrence of a hazard of a given magnitude in a given area, expressed as a percentage of loss (between 0: no damage, to 1: total damage) (Varnes, 1984). Although, conceptual frameworks for quantitative vulnerability estimations have been developed (Papathoma-Köhle et al., 2011), including more recent studies on uncertainty analysis (Eidsvig et al., 2014, Totschnig and Fuchs, 2013, Kaynia et al., 2008), there is still a great need for advancing methodologies in areas where they are essential for risk mitigation investments and improved decision-making. This study aims to develop a set of vulnerability curves for buildings impacted by debris flows in the Fella River Basin (Eastern Italian Alps). The area experienced a major rainfall event in August 2003 which triggered more than a thousand debris flows resulting in significant economic losses and two casualties. Two methodological approaches are applied for the estimation of process intensities: one based on dynamic run-out modeling (regional scale), and another based on interpretation of aerial and photographic documentation (local scale). The results are compared with damage values estimated shortly after the event, as well as vulnerability curves from the literature. Asset characteristics are collected through field work and desktop mapping, and population distribution and value for each building is calculated based on census and real estate data. The obtained vulnerability curves together with population distribution and building monetary value are subsequently used in an exposure and risk analysis at regional scale in Fella River Basin.

STUDY AREA

The study site (247 km^2) pertains to the Fella River Basin (Canal del Ferro and Val Canale, Eastern Italian Alps), a region environmentally (i.e. structural, lithological, morphological, climatic) prone to hazards such as debris flows and floods, flash-floods as well as earthquakes. The area presents high national interest due to its strategic position which resulted in time in urbanization and development of dense infrastructure networks (European communication and energy corridor) (Malek et al., 2014). Nevertheless, it has a low population density (between 2,26/km^2 in Dogna and 22/km^2 in Tarvisio, ISTAT 2014) with fluctuations during tourism activities – the main source of income for the inhabitants. The administrative units overlapping the study area are: Malborghetto-Valbruna, Pontebba, Tarvisio, and Dogna communes (Fig. 1).

Figure 1. (Left) The Fella River Basin Study area; (right) damages caused by the 2003 event in the study area (©Civil Protection, FVG)

The latest major hydro-meteorological event in the Fella area occurred in August 2003 (Fig. 1), when approximately 1 million cubic meter of debris flow deposits and river flooding produced damages to the infrastructure and buildings on an area of about 765 km^2, resulting in two casualties (Civil Protection, 2012). Reports of the Civil Protection show that the economic losses caused by this event in the Malborghetto-Valbruna, Pontebba, Tarvisio, and Dogna communes reach a total of 389 million Euros, out of which 49% was registered in Malborghetto Valbruna commune.

METHODOLOGY AND DATA

The methodological steps leading to the development of the vulnerability curves for both regional and local assessment approaches are presented in Figure 2. Two general sets of data were used, one leading to the estimation of process intensities (debris flow data) and the other, leading to the estimation of assets' degree of loss (buildings data).

Debris flow data

For the first approach (A, in Figure 2), the debris flow inventories were produced by the Italian Landslide AVI (CNR-IRPI, 2014) and IFFI Projects (ISPRA, 2014), Geological Survey of Friuli-Venezia Giulia Region (FVG), and landslide experts from the University of Trieste. The inventory contains 273 debris flow source area points and run-out polygons located mostly along the Val Canale slopes. Rainfall data (1976 – 2011) was used to determine three return periods by extreme value distribution analysis: 100 – 500 years for 'major' events (e.g. August 2003), 25 – 100 years for moderate' events (e.g. pre-2003 event), 10 – 25 years for minor' events (2003 - 2011 events), 1 – 10 years for 'frequent' events. Two Digital Elevation Models (2003, 2007) with a pixel size of 10 m were obtained from the Civil Protection of the FVG Region and utilized for the susceptibility and run-out analysis. The methodology developed by Hussin et al. (2013) was applied to generate a debris flow susceptibility map for the Fella River area. This map together with the event inventory map for different return periods were used to identify the release areas necessary for the run-out modeling. In addition to the high susceptibility class cells, the planar curvature and slope angle thresholds were employed to better define the source areas. The debris flow run-out modeling was performed using Flow-R (Horton et al., 2013), a software developed at the University of Lausanne, which uses a distributed empirical model for regional susceptibility assessments of debris flows. The model requires the minimum travel angle and the maximum velocity for each return period; these parameters were estimated based on back calibration of a limited number of events for each return period. Once the source areas maps for each return period were produced and integrated into the run-out model, the kinetic energy and maximum run-out probability were obtained.

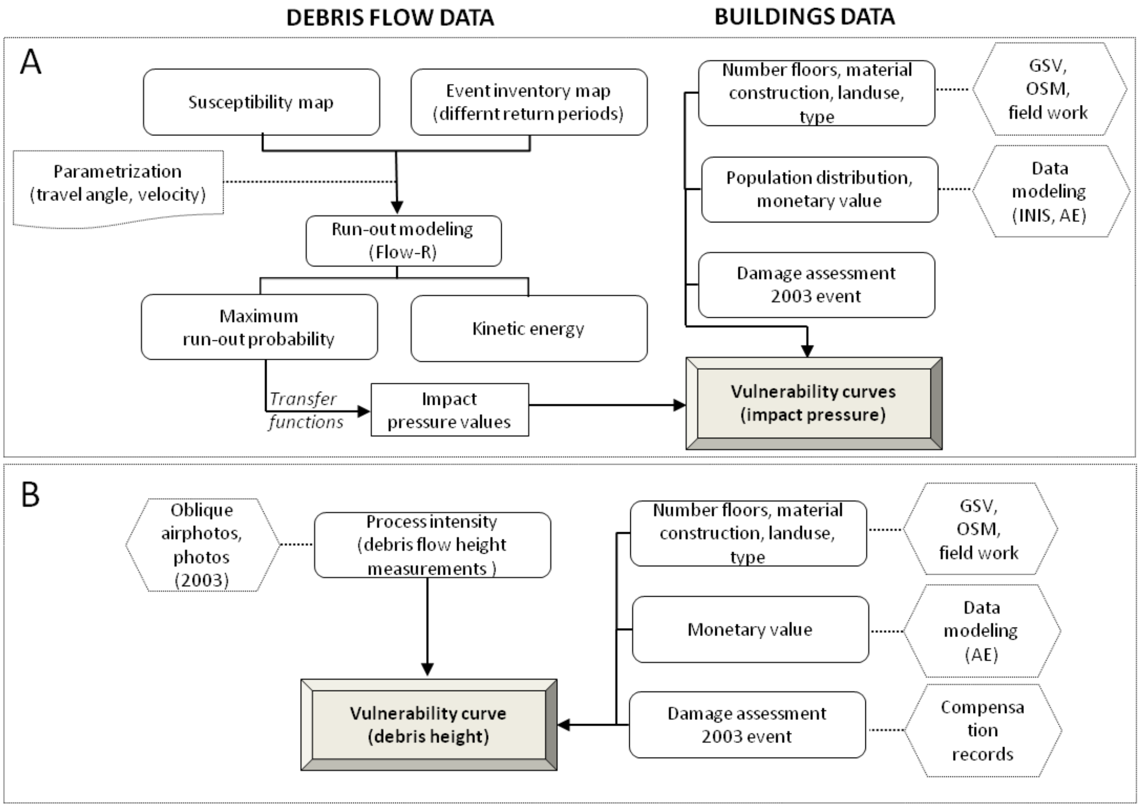

Figure 2. Methodological steps used for vulnerability assessment of buildings to debris-flows in Fella River Basin (A - regional scale: using dynamic run-out modeling; B – local scale: using photo-documentation)

In order to estimate the intensity value for the modelled runouts, the probability values were transferred into impact pressures using linear transfer functions. These functions are based on two factors: (1) the spatial distribution and variation of the probability values within the debris flow morphology (from the debris flow channels and transportation zones to the end of the deposit zones at the debris fans) and (2) the estimated impact pressures in the field based on damage assessments of past events.

In comparison with the first, in the second approach (B, in Figure 2) debris flow intensities were not modelled but estimated using a methodology developed by (Papathoma-Köhle et al., 2012). Information regarding the intensity was acquired from the interpretation of high-resolution oblique air photos and on-site photographic documentation of the resulting consequences collected by the Civil Protection of the FVG Region immediately after the August 2003 event. The height of the maximum debris and water flow was measured from the indicated marks on the building walls in relation with the building height. Following the intensity assessment, the recorded damages were analyzed and compared with compensation costs provided by the local authorities of Malborghetto Valbruna municipality for each affected building. The damage to the interior assets was not taken into account. After evaluating the impact on buildings and calculating the buildings value (see “Buildings data” section) the degree of loss was expressed as the percentage loss from the total building value. Each building was represented as a point in a XY coordinate system (x axis representing the intensity, y axis -, the degree of loss). Non-linear regression approaches can be applied to obtain best fitting functions. Cumulative distributions fulfil the mathematical requirements to model the vulnerability curves (define the depending variable i.e. degree of loss in a both sided confined interval [0, 1]; they are steady and monotonic increasing with the interval of its explaining variable i.e. intensity) (Totschnig et al., 2011).

Buildings data

An initial digital building dataset was provided by Civil Protection of the Friuli-Venezia Giulia region. The dataset contained information about the location (X, Y coordinates), geometry (height, area, volume, base and top elevation) and a general land use classification. As this information was not sufficient for vulnerability and risk assessment, firstly a survey was carried out using Google Street View for updating the building locations, and characterizing the building occupancy classes, building materials types and number of floors. Moreover, many of the buildings that were destroyed in 2003, or demolished later, had to be corrected, as well as the buildings that were constructed later had to be inserted. Subsequently, a fieldwork was carried out for validating the desktop mapping results using a mobile GIS application (Figure 3).

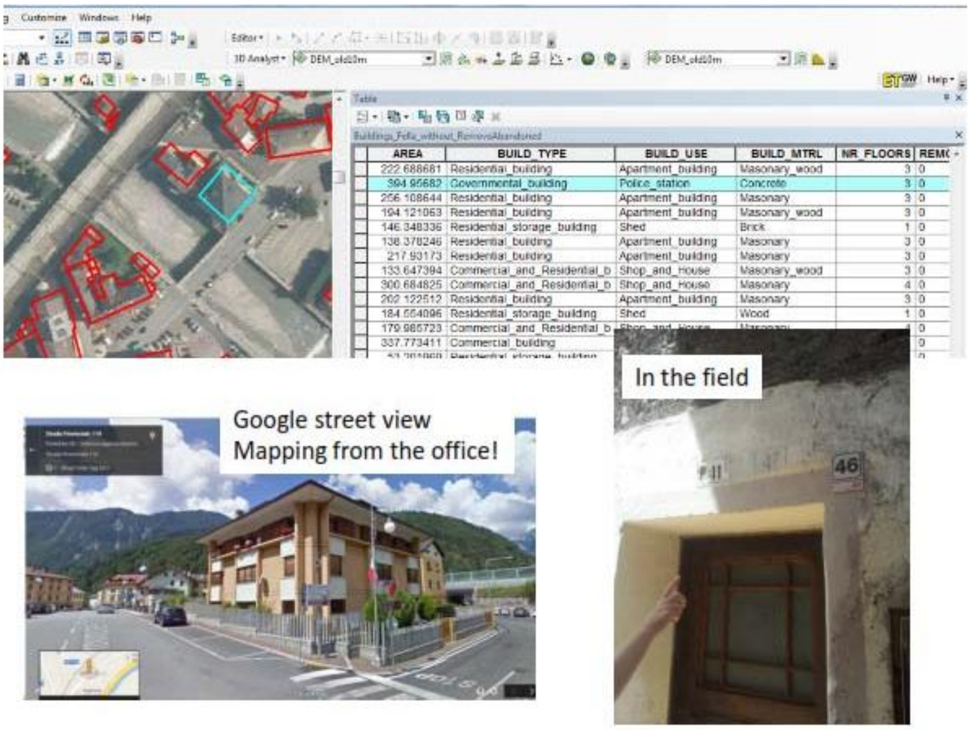

Figure 3. Update and validation of building inventory using Google Street View and field work

Additionally, population and building value information was generated based on existent data from the Italian National Institute of Statistics (ISTAT, http://www.istat.it/) and the Italian Revenue Agency (Agenzia delle Entrate, http://www.agenziaentrate.gov.it) as follows:

a) Population values available for the administrative units were subdivided over the buildings in the area, using a dasymetric mapping approach, taking into account the occupancy class (focusing mainly on residential buildings) and building size. Two different scenarios were taken into account for population modeling: one normal situation where most of the population is located in the residential areas, and a tourist season scenario, where also additional population is distributed over hotels and other tourist accommodations.

b) Minimum and maximum market values in Euro per Square meter (for the second semester of 2013) are given for different buildings with major land use types. These were further subdivided based on the zone where the buildings are located according to the Real Estate Observatory data (Osservatorio del Mercato Immobiliare, Agenzia Entrate – OMI) (center, periphery, rural zones). Based on the building footprint area, and the number of floors, the total floor space area was calculated, which was then multiplied by the minimum and maximum values, so that the result is the estimated minimum and maximum building value.

The population distribution and building value in the studied area was subsequently used to calculate the vulnerability, exposure and risk to debris flows and floods.

RESULTS

Regional scale vulnerability assessment using dynamic run-out modeling

Vulnerability curves for debris flow impact pressure and debris flow height were generated for 8 building types (which are a combination of the material type and the number of floors) (Figure 4). The curves based on debris flow height were developed partly based on available curves from the literature, and partly based on actual damage information from the 2003 event, combined with expert opinion. The maximum impact pressure found in the most extreme event with the lowest return period (100-500y) was 35 KPa, which caused the total destruction of several houses. Therefore, the maximum impact pressure for all other return periods does not exceed 35 KPa and is considered a cut-off value.

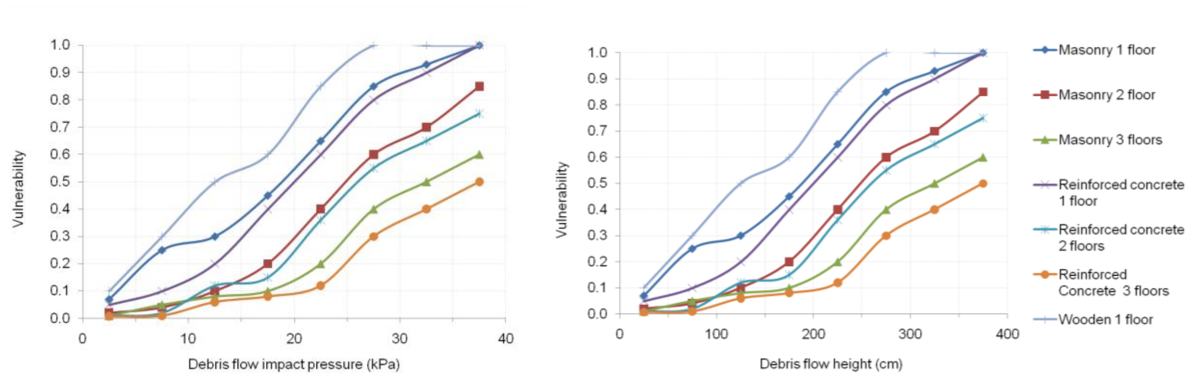

Figure 4. Debris flow vulnerability curves for impact pressure (left) and debris height (right)

Local scale vulnerability assessment using photo-documentation

A logistic distribution was applied in order to model the debris flow vulnerability curve (see Figure 5, Fella Data). The best fit parameters of the function (Equation 1) are given in Table 1.

$$P(t) = \frac{K \cdot P_0 \cdot e^{rt}}{K + P_0 (e^{rt} - 1)} \quad (1)$$

Where, P_0 = initial population, K = limiting value of P_0, r = growth rate, t = time. The coefficient of determination of the Logistic distribution is $R^2 = 0.959$.

Table 1 Logistic regression function best fit parameters

Parameter	Value
K	2.80E+05
P0	11396.94
r	1.72
t	0

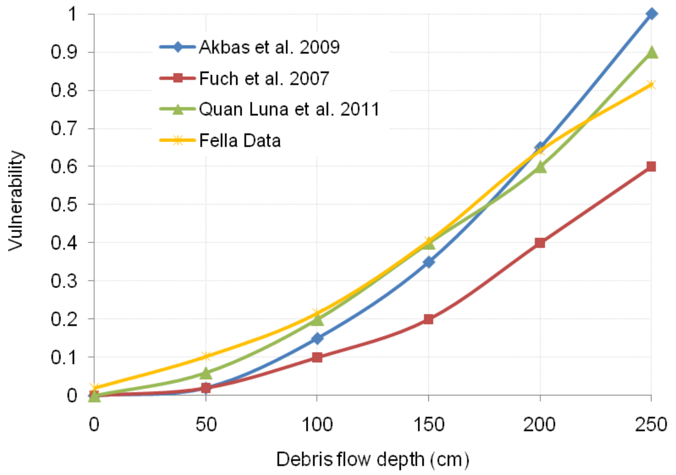

Figure 5. Debris flow vulnerability curve for debris height (Fella Data) in comparison with results from other similar case studies

Population distribution, buildings inventory and value

In the study area, the inventory contains 4778 buildings. The building landuse types were categorized in 16 classes. The residential and residential storage buildings are the most frequent occupancy types, with 39.5% and 41.8% respectively (Figure 6). The percentage distribution of the main occupancy types is reflected in the distribution of construction types: generally, the residential structures are masonry constructions (or a combination of masonry-wood or masonry-brick) (46.9%), whereas the majority of residential storage buildings (used as sheds, cabins, or garages) are made out of wood (38.4%). The schools, hospitals, municipal and governmental buildings are concrete or masonry constructions.

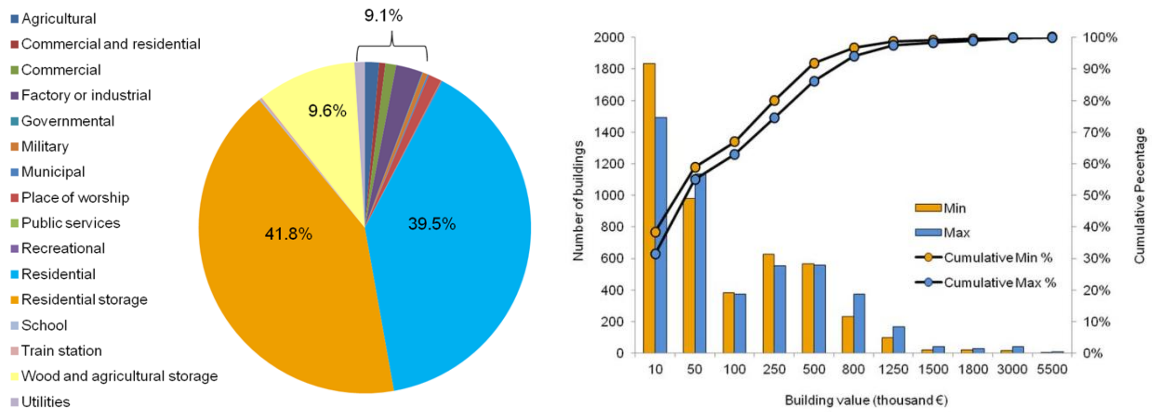

Figure 6. Percentage distribution of building occupancy types (left); variation in price for buildings grouped per value range (right)

The building height regime reflects indirectly not only the use but also the design restrictions given the seismic activity in the area. 60% of the buildings have only one level above the ground surface, meanwhile only 0.29% of the total (14 buildings) has over 4 floors (up to 6 floors). These latter buildings are used mostly as multi-storey apartment buildings.

As each building in the inventory had a minimum and a maximum value assigned, it was possible to calculate the variation in price for buildings grouped per value range. Figure 7 reflects the heterogeneity of buildings (in terms of use, material of construction, occupancy type, etc.) for value categories of less than 10.000, 10.000 - 50.000, 500.000 – 800.000,

800.000 - 1.250.000 Euros, although for the latter two the number of buildings is significantly lower compared with the former ones.
For the assessment of buildings exposure and risk we estimated the total worth of value (minimum, maximum) potentially damaged in each commune. For example, for the Malborghetto Valbruna commune, the total residential buildings value ranges between approximately 190 – 275 million Euros followed by commercial ones with 130 – 190 million Euros.
The calculated number of people per residential building use for each commune and scenario is presented in Table 2. The results show that in Malborghetto Valbruna, Pontebba and Tarvisio the population increases whereas in Dogna, the calculated number of people for both touristic and non-touristic season remains constant.

Table 2. Population distribution according to the building use taking into account two scenarios (A – non-tourisic season, and B – touristic season)

Building use	Malborghetto Valbruna		Pontebba		Tarvisio		Dogna	
	A	B	A	B	A	B	A	B
Apartment building	0	0	1202	1202	1914	1914	83	83
Holiday apartment	0	67	0	0	0	842	0	0
Holiday home	0	144	0	0	0	0	0	0
Hotel	0	284	0	164	0	289	0	0
House	955	955	194	194	1942	1942	104	104
Pharmacy & apartment building	0	0	6	6	0	0	0	0
Restaurant & apartment building	0	0	20	20	412	412	0	0
Shop & house	0	0	69	69	0	0	0	0
Shop & apartment building	0	0	0	0	234	234	0	0
TOTAL	955	1450	1490	1654	4503	5634	188	188
Total ISTAT (2014)	958		1481		4502		187	

DISCUSSION AND CONCLUSIONS

Vulnerability assessment represent an essential component of the for hazard risk analysis framework. In this study, we have applied two methodological approaches in order to quantify vulnerability of buildings to debris flow hazard using historical data and consequence information of the August 2003 hydro-meteorological event in Fella River Basin.
In the first methodological approach, the probabilities of a regional scale debris flow runout model were used to estimate intensity values expressed as impact pressures. The selection of transfer functions as well as the distribution of the Flow-R spatial probabilities must be further investigated in order to estimate the robustness of the model. Local scale dynamic runout models can be used to compare the runout probabilities with debris flow heights in a specific test area where more detailed data exists (see the work of Hussin et al., Abstract D03).
The empirical vulnerability curve generated with the second methodological approach was compared with other existing vulnerability curves such as the ones proposed by (Fuchs et al., 2007, Akbas et al., 2009, Quan Luna et al., 2011) for similar buildings and processes. The results for the Fella area show that the vulnerability values coincide in a good manner with the literature curves; however, a direct comparison must be carefully interpreted as the mathematical approaches and distributions are different. Another source of uncertainty is the fact that intensity was assessed in different ways for each case study (for example, Quan

Luna et al. (2011) modelled the debris depths). Moreover, the inexactness of debris height measurements represents a significant source of epistemic uncertainty.
In terms of buildings value and population distribution, it must be noted that building use and spatial distribution of population during touristic and non-touristic season are bounded to high variability. Nevertheless, comparing the official statistical data (INIS, 2014) with the calculated population distribution per type of residential building (only for non-touristic scenario), we can observe that the errors are negligible considering that the only input data was the total number of residents per commune.
To improve the current work, more research must be invested in transferring results from local to regional scale for both debris flow hazard modelling and vulnerability assessments. As briefly discussed, the model has limitations and it requires further investigation. However, the results can be readily applied in risk equations and provide to decision makers information regarding the costs of events for different process intensities in the future or under different development scenarios. As the implementation of risk reduction measures (structural mitigation works) in the study area after the 2003 event can change the intensity of future debris flows and thus assets' potential degree of loss and costs of reconstruction, the current methodology can be further improved and used for the estimation of future losses.

ACKNOWLEDGEMENTS

This work is a part of the CHANGES Project (Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists), a Marie Curie Initial Training Network, funded by the European Community's Seventh Framework Programme, FP7/2007–2013, under Grant Agreement No. 263953. The authors kindly acknowledge the support of the Civil Protection of Friuli-Venezia Giulia region and local authorities of Malborghetto Valbruna municipality for sharing the photo-documentation and damage information related with the August 2003 hydro-meteorological event.

REFERENCES

AKBAS, S. O., BLAHUT, J. & STERLACCHINI, S. Critical assessment of existing physical vulnerability approaches for debris flows. *In:* MALET, J. P., REMAITRE, A. & BOGAARD, T., eds. International conference - Landslide processes: from geomorphologic mapping to landslide modelling, 6–7 February 2009, 2009 Strasbourg, France. 229-233.

CNR-IRPI. 2014. *AVI Project* [Online]. Available: http://avi.gndci.cnr.it/en/archivi/frane_en.htm.

EIDSVIG, U. M. K., PAPATHOMA-KÖHLE, M., DU, J., GLADE, T. & VANGELSTEN, B. V. 2014. Quantification of model uncertainty in debris flow vulnerability assessment. *Engineering Geology,* 181**,** 15-26.

FUCHS, S., HEISS, K. & HÜBL, J. 2007. Towards an empirical vulnerability function for use in debris flow risk assessment. *Natural Hazards and Earth System Science,* 7**,** 495-506.

HORTON, P., JABOYEDOFF, M., RUDAZ, B. & ZIMMERMANN, M. 2013. Flow-R, a model for susceptibility mapping of debris flows and other gravitational hazards at a regional scale. *Nat. Hazards Earth Syst. Sci.,* 13**,** 869-885.

ISPRA. 2014. *The IFFI project (Inventory of Landslide Phenomena in Italy)* [Online]. Available: http://www.isprambiente.gov.it/en/projects/iffi-project.

ITALIAN NATIONAL INSTITUTE OF STATISTICS (ISTAT) [Online]. Available: http://www.istat.it/

KAYNIA, A. M., PAPATHOMA-KÖHLE, M., NEUHÄUSER, B., RATZINGER, K., WENZEL, H. & MEDINA-CETINA, Z. 2008. Probabilistic assessment of vulnerability to landslide: Application to the village of Lichtenstein, Baden-Württemberg, Germany. *Engineering Geology,* 101**,** 33-48.

OSSERVATORIO DEL MERCATO IMMOBILIARE (OMI), Agenzia Entrate (Italian Revenue Agency), http://www.agenziaentrate.gov.it,

MALEK, Ž., SCOLOBIG, A. & SCHRÖTER, D. 2014. Understanding Land Cover Changes in the Italian Alps and Romanian Carpathians Combining Remote Sensing and Stakeholder Interviews %M doi:10.3390/land3010052 %U http://www.mdpi.com/2073-445X/3/1/52. *Land %@ 2073-445X,* 3**,** 52-73.

PAPATHOMA-KÖHLE, M., KAPPES, M., KEILER, M. & GLADE, T. 2011. Physical vulnerability assessment for alpine hazards: state of the art and future needs. *Natural Hazards,* 58**,** 645-680.

PAPATHOMA-KÖHLE, M., KEILER, M., TOTSCHNIG, R. & GLADE, T. 2012. Improvement of vulnerability curves using data from extreme events: debris flow event in South Tyrol. *Natural Hazards,* 64**,** 2083-2105.

QUAN LUNA, B., BLAHUT, J., VAN WESTEN, C. J., STERLACCHINI, S., VAN ASCH, T. W. J. & AKBAS, S. O. 2011. The application of numerical debris flow modelling for the generation of physical vulnerability curves. *Nat. Hazards Earth Syst. Sci.,* 11**,** 2047-2060.

TOTSCHNIG, R. & FUCHS, S. 2013. Mountain torrents: Quantifying vulnerability and assessing uncertainties. *Engineering Geology,* 155**,** 31-44.

TOTSCHNIG, R., SEDLACEK, W. & FUCHS, S. 2011. A quantitative vulnerability function for fluvial sediment transport. *Natural Hazards,* 58**,** 681-703.

VARNES D. 1984. Landslide hazard zonation: a review of principles and practice. UNESCO, Paris