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FLOOD DAMAGE ASSESSMENT AND UNCERTAINTY ANALYSIS: THE CASE STUDY OF 2006 FLOOD IN ILISUA BASIN IN ROMANIA

Raffaele ALBANO[1], Iulia CRĂCIUN[2], Leonardo MANCUSI[3], Aurelia SOLE[1] & Alexandru OZUNU[2]

[1]*University of Basilicata, School of Engineering, 10 Ateneo Lucano Street, 85100 Potenza, Italy, raffaele.albano@unibas.it*

[2]*Babes-Bolyai University, Faculty of Environmental Science and Engineering, 30 Fântânele Street, 400294, Cluj-Napoca, România, iulya_craciun@yahoo.com*

[3]*Sustainable Development and Energy Resources Department, Research on Energy Systems SpA, 54 R. Rubattino, 20134 Milano, Italy, leonardo.mancusi@rse-web.it*

Abstract: Flood damage assessments supply crucial information to support authorities, local entities, and the stakeholders involved in decision-making regarding flood risk management in their compliance with the Floods Directive (2007/60/EC). Specifically, the estimation of economic flood damage provides objective results and rational procedure in so that relate legislative planning instruments in flood risk management can be understood, accepted and shared among stakeholders. However, flood damages assessment is specifically tailored to characteristics of the flooding and objects in the considered country. Moreover, the necessary information for this analysis are not always available for all European Countries, in particular regarding the damage functions which assumptions have large effects on flood damages estimation; therefore, the existence of uncertainties that may affect the final choice needs to be considered as in any decision process. In this paper, we have made an attempt to use different damage functions, collected and harmonized by the European Joint Research Centre (JRC), utilized in several European countries, for the flood losses assessment in Romania where these functions are not available. Moreover, we have compared the assessed damage obtained through the use of the JRC damages functions and real, surveyed damage in a case study in North-Western Romania, (i.e. Ilișua Basin), regarding the flood that occurred in June 2006, and analyze uncertainties. The performed analysis has demonstrated that the outcomes are influenced by the selection and testing of vulnerability curves. Our results show that overall applicability and transferability of depth-damage curves to other geographical regions is still a major gap in current flood damage modeling, but the quantification of the uncertainties and its communication to stakeholders are the first step for the maximization of effectiveness of quantitative approach, towards flood risk management objectives of the Flood Directive, ensuring that risk information is robust, credible and transparent.

Keywords: flood damages assessment; uncertainty analysis; Flood Directive; depth-damage functions; GIS.

1. INTRODUCTION

In recent years, studies (te Linde et al., 2011; Bubeck & Kreibich, 2011; Bubeck et al., 2011; Escuder-Bueno et al., 2012; Arghiuș et al., 2014) have shown that both frequency and economic damage caused by floods are increasing both in Europe and the world and are expected to increase over time with climate change and land use.

Some examples include the UK floods of October and November of 2000, which caused damages of about 1.5 billion US$; the floods from 2002, being one of the most extreme flood event that caused great damages in Europe, i.e. 16.5 billion US$ (Barredo, 2006; Messner et al., 2007); the flood from 2010 in Belgium with damages of around 238 million US$; the flood from 2010 in Romania with damages of around 1.1million US$. More recently the floods from June 2013 in central Europe caused damages of approximately 13 billion US$, only in Germany the losses being of 12.9 billion US$ (de Moel et al., 2015). These catastrophic events led to an increased interest in the concept of flood risk management, (de Moel & Aerts, 2010), as demonstrated by the adoption of Directive 2007/60/EC of the European Parliament and Council, which further was adopted by each Member State (EU Directive 2007/60/CE, 2007).

According with the Flood Directive (FD) 2007/60/EC, risk management is based on a comprehensive analysis that includes not only the hazard side, but also of the possible consequences and an appraisal of potential risk reducing measures. Knowledge of potential direct damages from flood hazards is important, among others, to examine the effectiveness of hazard mitigation strategies and to prioritize investments, comparing impacts of different management strategies in order to select the economic optimal protection standards for flood defenses.

In this context, the Directive offers general guidelines like the necessity of developing flood hazard and risk maps and management plans in each country, but it doesn't specify the methods or the approaches that can be applied in order to achieve this goals. Therefore, every country developed different methods and models on the basis of the context of the conditions (e.g. geographical, geomorphological and socio-economic) and of knowledge present.

However, the implementation of the FD and its review/update every 6 years provides an opportunity to revise the model of flood risk governance and confront the shortcomings encountered on the bases of more appropriate and advanced tools; this improving process should be oriented to the development of a flexible but consistent and transparent European framework that applies best practice from existing models while providing room for including necessary regional adjustments and integrating uncertain figures into their decision making process.

After this brief introduction, the paper introduces to the growth of the Flood Risk Governance in Romania to understand the context of the conditions and of knowledge present in the country and, therefore, the challenge and opportunities that the FD could provide (Sect. 2). In this light, we have made an attempt to implement a quantitative risk assessment approach (a synthesis of the conceptual framework is described in Sect. 3) that should increasingly be used, in addition to the traditional qualitative methods, because it is able to support decision making in prioritizing investments and cost-benefit analysis of mitigation alternatives, as prescribed by FD. In particular, the authors have used different damage functions, utilized in several European countries, that have been collected and harmonized by the European Joint Research Centre (JRC), (Huizinga, 2007), for the flood losses assessment in a case study in the North-Western Romania (Sect. 4), where these functions are not available.

Moreover, we have compared the assessed damage obtained through the use of the JRC damages functions and real, surveyed damage in the Romania case study (regarding the flood that occurred in June, 2006) performing an uncertainty analysis (Sect. 5). Finally, conclusion and remarks are presented in Sect. 6.

2. FLOOD RISK GOVERNANCE IN ROMANIA

The first legal attempt to regulate the floods in Romania was represented by the Water Law 107/1996. The aim of the Water Law beside the protection of water resources, water protection against pollution, aquatic ecosystem protection, was flood defense. However, regarding the flood defense, the document was poor in details pointing out just the need for structural defense measures, prevention and intervention measures, as well as the need for strategies elaboration (Water Low 107/1996, art.67). Over time the Water Law was amended and completed (e.g. by Law 310/2004, by Law 112/2006) in order to improve and respond to the need of flood risk reduction.

The need of new law implementation in Romania was highlighted by the flood events in the last years that produced great damages (Arghiuș et al., 2011). For instance, the flood from April 2000 on CrișulAlb Basin in east of the country produced total damage of 5.5 million euro; the flood from August 2002 on Slanic River, Buzau County with precipitation exceeding 100 l/m^2 caused damages of 292 500 euro; the floods from July 2008 on the Suceava, Moldova and Bistrița Rivers from the Siret Basin caused great damages, on the Suceava River the historical rates being exceeded, 107 cities were affected and the reported damages being around 200 million euro. Also the floods from 2010 with damages of 800 million euro affected 37 counties in Romania.

In this light, the concepts of risk management have continued to evolve; in particular, the need of a comprehensive and holistic approach regarding the flood risk management, that could support decision makers in prioritize intervention and in selecting alternative risk mitigation options, was pointed out. As a result, in 2010, the Water Law 107/1996 was further change through the H.G. 846/2010, the main aim being the mitigation of damages and life loss prevention. This results aim to address at national level the implementation of the Directive 2007/60/EC regarding the National Strategy for Flood Risk Management for medium and long term. In order to respond to the requests of the Flood Directive (FD), flood risk management plans that include the elaboration of hazard and risk maps were developed at a national level (I.N.H.G.A., 2016).

The implementation process contained three stages: preliminary flood risk assessment, development of hazard maps and flood risk maps, and the final stage regarding the development of flood risk management plans. All this stages were accomplished and as a result The National Plan for prevention, protection and mitigation of flood effects was developed. However, this plan focus more on the hazard and exposure components of the risk, and less on the vulnerability and thus on consequences, mainly due to limitations in available data and knowledge on damage processes and influencing factors (Arghiuș et al., 2014); this is also, because the assessment of direct costs is not only natural hazard specific, but also specific for different sectors or elements at risk in defined regions or countries.

However, it is acknowledged all three risk components (hazard, exposure, vulnerability) of flood risk assessment should be analyzed in order to provide objective results and rational procedure for quantitative risk and cost-benefit analysis, as prescribed by the FD: according to Art. 7 of the Directive 2007/60/EC, FRMP have to include measures for flood risk reduction, taking also into account “relevant aspects such as costs and benefits”.

Hence, it is evident that only traditional qualitative risk assessments, commonly used in Romania, are not alone sufficient to comply with these prescriptions and that more sophisticated quantitative methods should be adopted.

This requires a combination of more efficient methods and technologies that are able to express the uncertainty but also to reduce it, by establishing a coherent framework for the data collection and evaluation; therefore, the flood risk management can be understood, accepted and shared among stakeholders.

3. QUANTITATIVE FLOOD RISK ASSESSMENT: THE CONCEPTUAL FRAMEWORK

In flood risk management, flood risk can be understood as the intersection of the following factors: *hazard*, *exposure*, and *vulnerability*, forming a ‘risk triangle’. The hazard refers to the frequency and intensity of a possible flood event; exposure refers to the people, economic assets and goods exposed to hazards; and vulnerability refers to the susceptibility and value of the receptors potentially affected by floods (de Moel et al., 2015; Kaźmierczak & Cavan, 2011).

Flood damage can be classified into (Merz et al., 2010; Bubeck & Kreibich, 2011; Jongman et al., 2012; Meyer et al., 2013): direct tangible (direct damage which can be monetary quantified; e.g. damage to buildings and content, destruction of infrastructure or harvest); direct intangible (direct damage, difficult to quantify in monetary terms; e.g. loss of life); indirect tangible (indirect damage which can be monetary quantified; e.g. production loss, cost of traffic disruption); indirect intangible (indirect damage difficult to quantify in monetary terms; e.g. trauma). Even though intangible and indirect damages can account for a large share in the total flood impact (Penning-Rowsell et al. 2010; Albano et al., 2014), this study included only the assessment of direct tangible damages.

According to these definitions, the procedure for risk assessment consists essentially of (i) the hazard assessment, aimed at analyzing the hydrological and hydraulic characteristics of the river basin (Sole et al., 2013) and (ii) the assessment of potential damage as a function of exposure and vulnerability (i.e., susceptibility and value of assets) in flood prone areas (Fig. 1). In particular, the exposure is represented by the assets at risk, which are classified usually on the basis of economic sectors (e.g. buildings, infrastructure and agriculture). Moreover, the value of these assets can be determined in two ways: depreciated values, i.e. the actual value of the good when the flood damage occurs, and replacement values, i.e. value of replacement of the old goods that were damaged by new ones, (Merz et al., 2010). Finally, the susceptibility of the assets at risk relates the damages of the assets at risk to flood characteristics, using damage functions. The most common and internationally-accepted approach in damage functions is based on depth-damage curves, i.e. a function of the type or use of the building and the inundation depth. Damage functions can be differentiated in *relative damage function*, showing the expected damage as a proportion of the total value, and *absolute damage functions*, indicating the damage in monetary terms (Messner et al., 2007; Jongman et al., 2012; de Moel et al., 2015).

The European Commission Joint Research Center (JRC) made a first attempt to develop a pan-European damage model, by collecting and harmonizing depth-damage curves and asset values for several European countries (Huizinga, 2007). The obstacle in this kind of approaches is the increased uncertainties associated with input data, depth-damage functions, value of the assets.

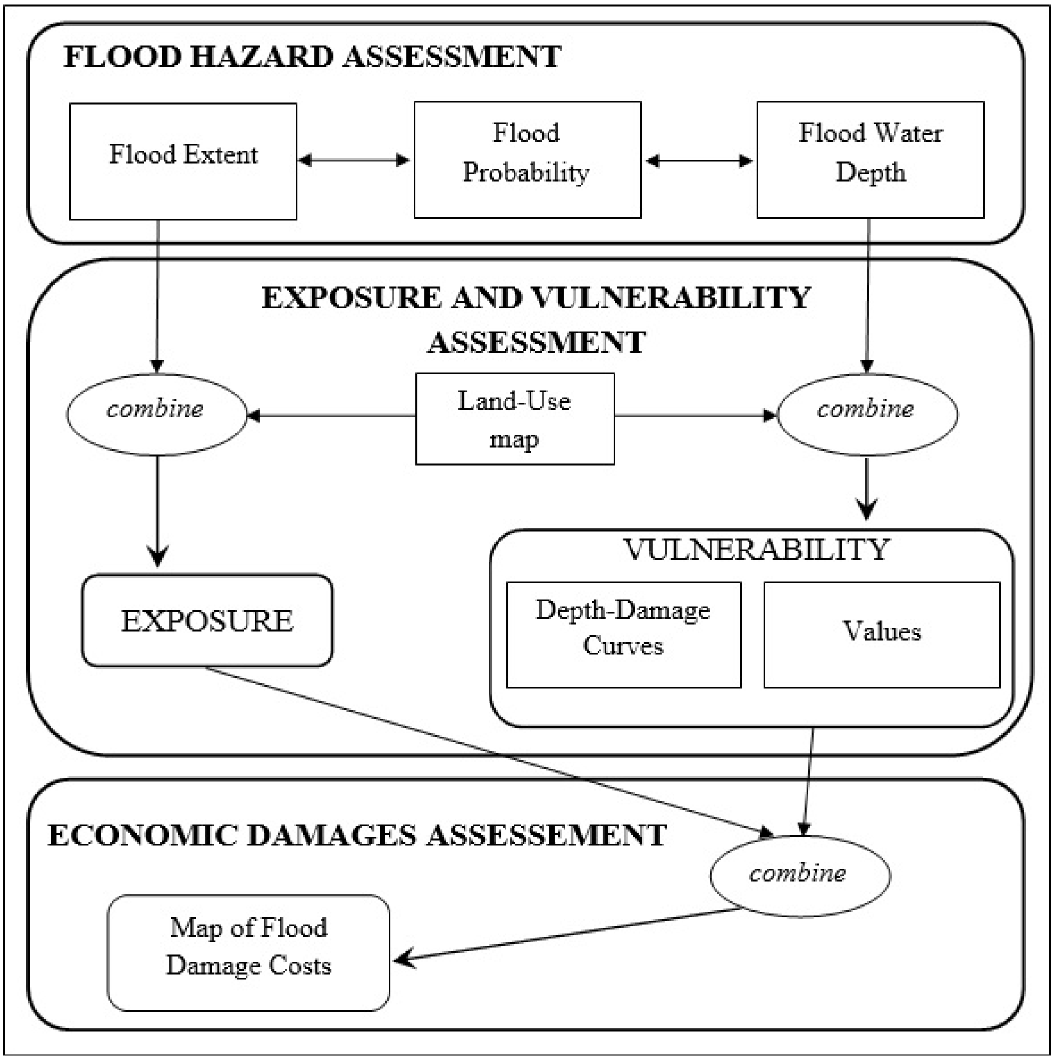

Figure 1. Schematic representation of performed flood damage assessment

4. THE APPLICATION OF QUANTITATIVEAPPROACH IN ROMANIA

Romania, like other European countries, hadn't available the necessary information to develop damage functions, due to the variation in exposed elements among this county and also because the existing large-scale databases are too poor to support the development of new country-specific curves characterized by a good degree of accuracy and that have a statistical meaning.

In order to perform the damage estimation for Romania, we applied the seven JRC functions from literature (Huizinga, 2007) and showed that the outcomes are strongly influenced by the shape of depth-damage functions. The main steps of this analysis are presented in figure 1 and described in the following sub-sections. Moreover, in literature (Scorzini & Frank, 2015; Jongman et al., 2012; de Moel & Aerts, 2011; Cammerer et al., 2013; Albano et al., 2015a) it has been showed that the transferability of models and implicitly of damage functions from one region to another can be the source of important uncertainties. Hence, we have performed an uncertainty analysis comparing the assessed damage obtained through the use of JRC damages functions and real, surveyed damage of the proposed case study in North-Western Romania, i.e. Ilișua Basin, regarding the 2006 flood event.

4.1. Study Area

The event considered in this case study is the flood that occurred in the Ilișua Catchmentin June, 2006. This catchment, (Fig. 2), is located in North-Western Romania, has a surface of 353 km^2 and a mean altitude of 493 m. The principal river is Ilișua with a total length of 52 km. The flood that occurred on June 21st 2006 was characterized by a peak flow of Qmax=280m^3/s (calculated in a section locaded in the middle of the basin).This corresponds to an occurrence propability of 0.7 – 0.8% (125 – 140 years return period).

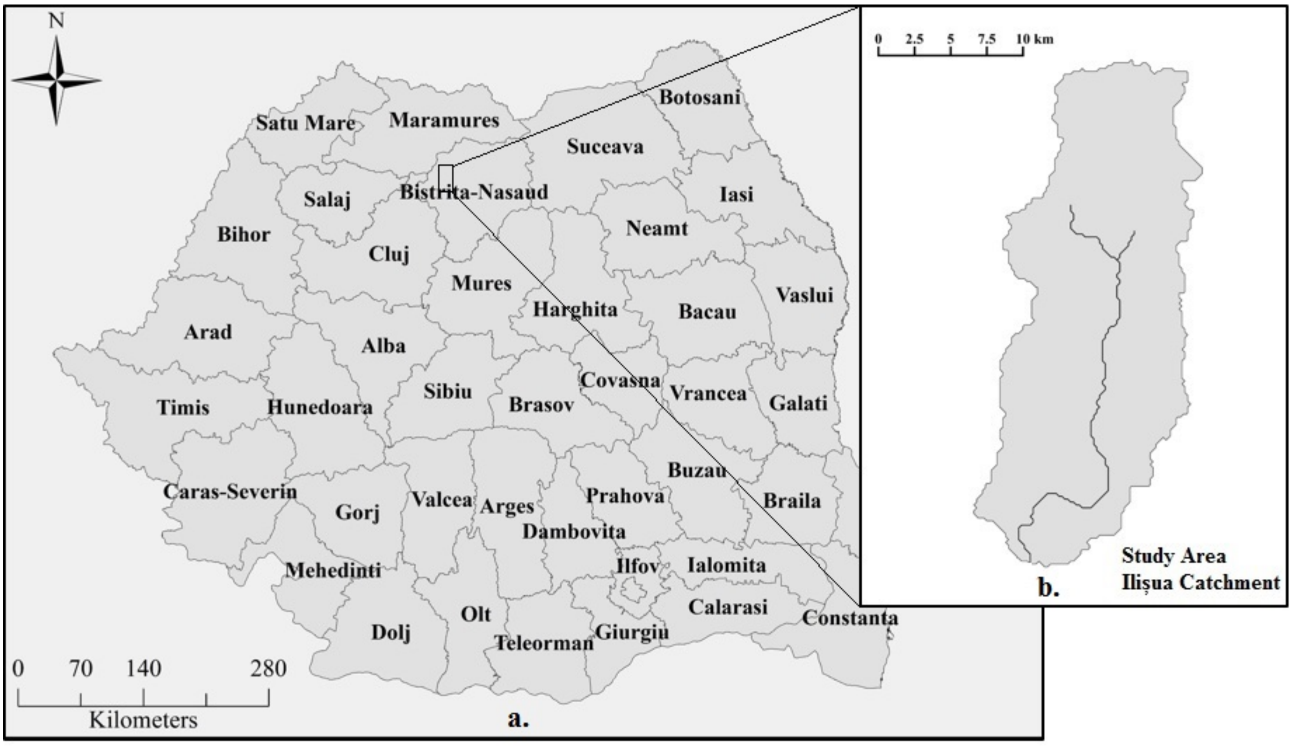

Figure 2. a. Romanian map; b. Study area: Ilișua Catchment

The effects were severe, with 13 deaths and significant structural damages (Sofronie et al., 2013). For this analysis six main affected villages were considered: Cristeștii Ciceiului, Ilișua, Căian, Lunca Borlesei, Spermezeu, Borleasa. The real, surveyed damage data was presented in the Coverage and Risk Assessment Plan of Bistrița-Năsăud County, (2006) of the County Committee for Emergency Situations Bistrița-Năsăud. The total registered damages for the analyzed area was 1.1 million euro, as following: for buildings/urban, 194 thousand euro; for roads, 687 thousand euro; for agriculture, 127 thousand euro.

4.2. Hazard analysis

The first step in flood risk assessment is the hazard analysis in which the flood extent and water depth are calculated. QGIS (Geographic Information System) and HEC RAS (Hydrologic Engineering Center's River Analysis System) software were used to estimate flood hazard. The input data (e.g. the topographic map, the cross-section of the river, the land use map etc.) were provided by the Romanian Waters National Administration of Someș-Tisa Water Branch. Using the topographic map as a background, which is at the scale 1:5000, the contour lines, the elevation points and the river centerline were digitized. By interpolation along the river centerline between two subsequent contour lines, elevations of the river thalweg were calculated. These data were used to create a digital elevation model using the "Raster - Interpolation" QGIS plugin. Triangular interpolation (TIN) method were used, and Cellsize X and Y of 5 m were adopted. Given the fact that only nine measured cross-sections of the river were available, more cross-sections were created based on the DEM using the Q-RAS tool of QGIS. For the hydraulic simulations, the 1D hydraulic model HEC RAS (Fig. 3) was used and the flow profile was developed. The initial and boundary conditions that were used are: Q = 280m^3/s, flow conditions – critical depth upstream and normal depth downstream, mixed flow regime.

The discharge (flow) of 280 m^3/s is the estimated value for the event of June 21st 2006 at a stream gauge in the middle of the basin.

Using the RAS Mapper tool of the HEC RAS software the results were transformed in a 2D grid and a raster file containing the maximum water depth value for every flooded grid was created. RAS Mapper tool is, in fact, capable of producing the spatial interpolation of water level output results from 1D RAS simulations to a file raster format. Subtracting the elevations of the terrain in raster file format from the spatial interpolation of water level, it is possible to get the raster of water depth. This raster represents the hazard map and it is one of the input data utilized in the damage model.

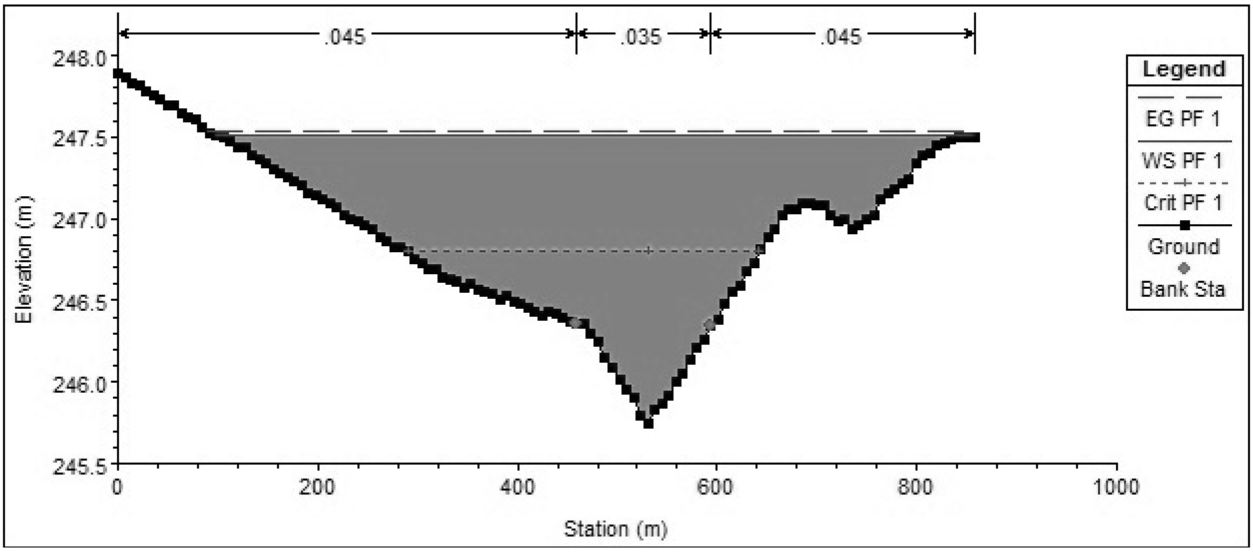

Figure 3. HEC RAS data processing.

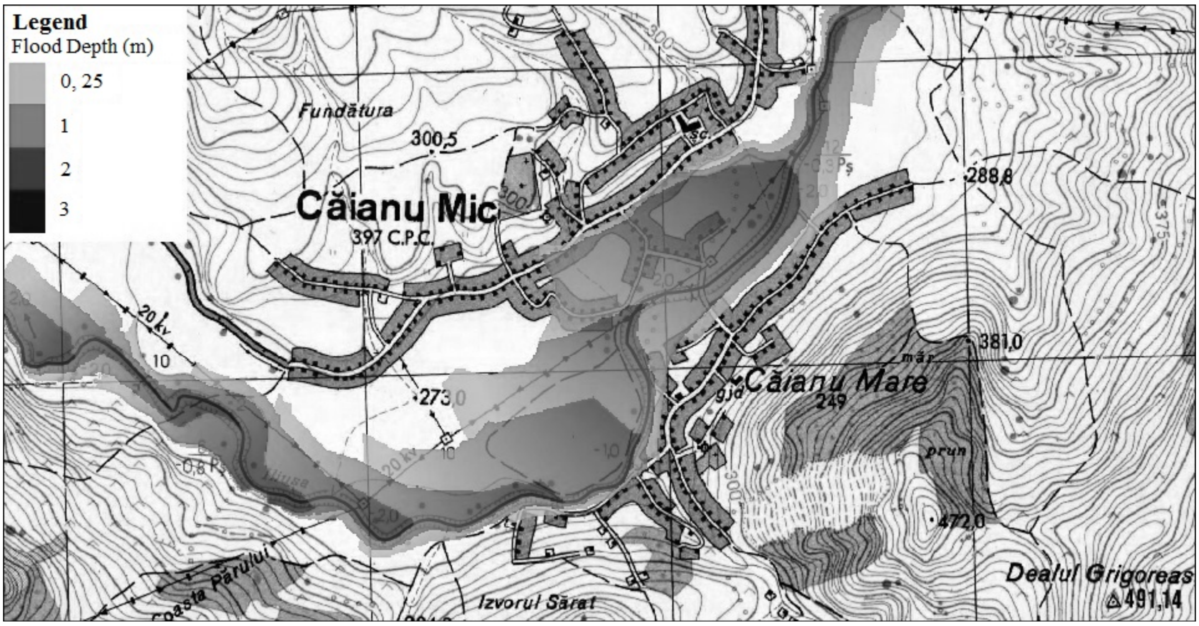

Figure 4. Flood Hazard Map for the city of Căianu Mic, developed in this study using the HEC-RAS software

4.3. Exposure and Vulnerability analysis

The exposure analysis refers to the elements at risk, which are obtained by overlapping the information about assets present in the area (e.g. land-use map and roads map) with hazard information (e.g. flood extent and water depth) (Fig. 4).

At meso-scale, usually, the assets with similar characteristics are in aggregated form (e.g. land use maps); in this case study we used the CORINE land cover database.

Then, a value (i.e. the *asset value*) was determined for each class of CORINE map. The data regarding the assets value were provided by the local municipalities of the affected villages. The data were documented in 2012, therefore giving the fact that the event took place in 2006, the inflation from 2006 to 2012 must be calculated in order to correct the values. For this purpouse the GDP deflator is used, which is a measure of price inflation. Thecalculated value in euro per square meter for each CORINE land-use class, exposed to flooding for the selected case study, are presented in table 1.

The set of depth-damage functions, developed by JRC for different European Countries (Huizinga, 2007), are, furthermore, associated to each land-use class of CORINE, affected by flood in the selected case study. The JRC's actions developed EU-wide methodologies to prevent and predict natural hazards, with the aim of producing depth-damage functions for the assessment of direct damage produced by floods. In Huizinga (2007), the proposed depth-damage curves are relative to 5 macro-classes of land use classes: residential buildings, industry, commerce, infrastructure and agriculture. Hence, we adjusted the JRC depth-damage curves to enable their application with the CORINE land use maps: we associated the depth-damage curves of Huizinga 2007 to the CORINE land-use class that was considered by authors to be most comparable, as shown in table 2. For instance, for the CORINE class "discontinuous urban fabric" it was attributed the "residential building" class from JRC and its coresponding depth-damage functions; and so on.

Moreover, we have added manually main roads, i.e. digitizing the roads from the topographic map provided by the Romanian Waters National Administration of Someș-Tisa Water Branch, and were assigned to them the “Road and rail networks and associated land” class and associated the asset value provided by the Romanian Waters National Administration of Someș-Tisa Water Branch.

4.4. Damage analysis

The damages of the event were estimated using the free and open source tool *FloodRisk* (Mancusi et al., 2015) developed in QGIS platform. The tool calculates both direct tangible damage (damage to structure) and direct intangible damage (loss of life) caused by floods and visualizes them in form of tables, graphs and maps. Maps give a direct and strong impression of the spatial distribution of the flood risk, providing essential information to stakeholders (Albano et al., 2015b).

Table 1. Land use classes reclassification and site-specific assets value for the selected case study.

Code	Description CORINE land use classes	Assets value (euro/m²)
112	Discontinuous Urban Fabric	108
122	Road and rail networks and associated land	16
211	Non-irrigated Arable Land	0.08
231	Pastures	0.06
242	Complex Cultivation Patterns	0.16
243	Land Principally Occupied by Agriculture with significant areas of natural vegetation	0.13
311	Broad-Leaved Forest	0.04
312	Coniferous Forest	0.04
313	Mixed Forest	0.04
321	Natural Grassland	0.06
324	Transitional Woodland-shrub	0.06
331	Beaches Dunes and Sand Plains	0.06

Table 2. Correspondences between JRC depth damage curves and Corinne land-use classes.

CORINE land use classes	JRC depth-damage curves classification on the basis of economic sectors
Discontinuous Urban Fabric	Residential buildings
Road and rail networks and associated land	Infrastructure
Non-irrigated Arable Land	Agricultural
Pastures	Agricultural
Complex Cultivation Patterns	Agricultural
Land Principally Occupied by Agriculture with significant areas of natural vegetation	Agricultural
Broad-Leaved Forest	Agricultural
Coniferous Forest	Agricultural
Mixed Forest	Agricultural
Natural Grassland	Agricultural
Transitional Woodland-shrub	Agricultural
Beaches Dunes and Sand Plains	Agricultural

We estimate the direct damage for the selected flood event using the seven depth-damage functions proposed by the JRC, along with an uncertainty analysis regarding the functions transferability in space. The aim of this analysis is to determine the effect on the results if applying different damage functions from other counties in another context then the one for which they were developed. For each exposed element, i.e. the CORINE land use described in table 2, the damage was calculated using the JRC depth-damage functions and the asset value provided by and adjusted to enable their application in the Romania case study for the comparison with the real flood event of June 2006 in Ilișua Basin.

Further, because the real, surveyed damage data refers to three classes (urban, roads and agriculture) the results of the simulations have been grouped according to these classes to ensure a consistent comparison between the calculated damage assessment and real, surveyed damage in a case study in North-Western Romania, i.e. Ilișua Basin, regarding the flood that occurred in June 2006.

In table 3, the damages calculate with the seven JRC depth-damage curves available in Huizinga (2007) for various European Countries (i.e., Belgium, Czech Republic, Germany, Netherlands, Norway, Switzerland, UK) and the real surveyed damages, (i.e. Surveyed Ilișua Basin), reported by Coverage and Risk Assessment Plan, 2006 of the County Committee for Emergency Situations Bistrița-Năsăud, are presented. The surveyed urban damage is higher than agriculture flood losses, fact that is captured as well by all the model simulation with the use of the seven JRC curves. However, this is not happening also with the infrastructure damages which represent a great share of the total damage. The damage estimated for this class with the JRC function strongly underestimates the corresponding real, surveyed losses. Moreover, the model systematically overestimates the urban and agricultural real losses. This fact shows that the estimations of infrastructure damages is less developed and can lead to large uncertainties.

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In table 3, the damages calculate with the several depth-damage curves available in Huizinga (2007) for various European Countries (i.e., Belgium JRC, Czech Republic JRC, Germany JRC, Netherlands JRC, Norway JRC, Switzerland JRC, UK JRC) and the real, surveyed damages (i.e. Surveyed Ilișua Basin), reported by Coverage and Risk Assessment Plan, 2006 of the County Committee for Emergency Situations Bistrița-Năsăud, are presented. The surveyed urban damage is higher than agriculture flood losses, fact that is captured as well by all the model simulation with the use of the seven JRC curves. However, this is not happening also with the infrastructure damages which represent a great share of the total damage. The damage estimated for this class with the JRC function strongly underestimates the corresponding real, surveyed losses. Moreover, the model systematically overestimates the urban and agricultural real losses. This fact shows that the estimations of infrastructure damages is less developed and can lead to large uncertainties.

Table 3. Results of damage calculation using different JRC depth-damage functions and the real, surveyed damages reported by Coverage and Risk Assessment Plan, 2006 of the County Committee for Emergency Situations Bistrița-Năsăud.

	Damages (MEuro)			
	urban	**roads**	**agriculture**	**Total**
Belgium	8.3	0.09	0.85	9.2
Czech Republic	5	0.14	0.69	5.8
Germany	3.8	0.16	0.31	4.3
Netherlands	3.2	0.10	0.81	4.2
Norway	18.4	0.26	0.69	19.4
Switzerland	13.8	0.13	0.58	14.6
UK	32.4	0.13	1	33.6
Surveyed Ilișua Basin	**0.29**	**0.6**	**0.12**	**1.1**

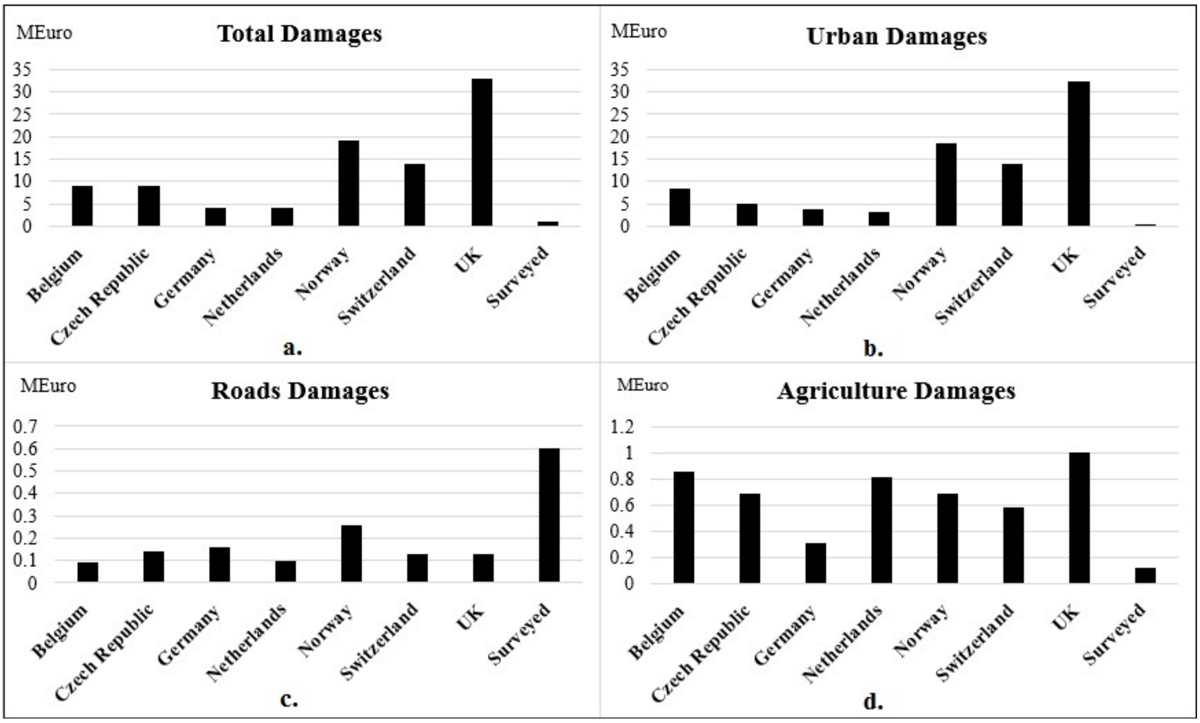

Figure 5. Graphic representation of the results of damage calculation using different JRC depth-damage functions and the surveyed damages reported by Coverage and Risk Assessment Plan, 2006 of the County Committee for Emergency Situations Bistrița-Năsăud; a. Total damages, b. Urban damages, c. Roads damages, d. Agriculture damages.

5. UNCERTAINTY ANALYSIS

According to table 3 and figure 5, a large variability in the results can be observed (between 4 and 33 million Euro). Hence, in order to analyze the uncertainty regarding the damage functions transferability we compared the results of the simulated damage assessments, performed using the *FloodRisk* tool, and the reported damages of the 2006 flood of Ilișua Catchment, located in North-Western Romania, provided by County Committee for Emergency Situations Bistrița-Năsăud for Ilișua Basin 2006 flood.

We have performed this comparison by dividing each damage value estimated for each of the seven JRC depth-damages curves to the real, surveyed damage result (Table 4). This ratio, called relative error, indicates error rate of the simulated damage respect to the surveyed damage. The minimum relative error was obtain when using the Netherlands-JRC functions (37%) comparing with the large errors of Norway-JRC, Switzerland-JRC and UK-JRC functions. In agreement to other studies from literature (e.g. Merz et al., 2004; Jongman et al., 2012), the model damage assessment calculated with the JRC curves tends to overestimate the results in our case study. The large variation in the results and the large relative errors are mostly related to the shape of depth-damage functions (Jongman et al., 2012, Messner at al., 2007, de Moel & Aerts, 2011). Indeed, the damage factor reaches 100% for a water depth of 3 m in the case of the UK functions for urban land-use class, while in the case of Netherlands functions, the damage factor is around 20%at a water depth of 3 m.

Table 4. Relative error and function uncertainty determination

Damage Functions	Total damages (MEuro)	Relative error	Function uncertainty
Belgium-JRC	9.2	**8.37**	**2.21**
Czech Republic-JRC	5.8	**5.28**	**1.39**
Germany-JRC	4.3	**3.92**	**1.03**
Netherlands-JRC	4.2	**3.79**	**--**
Norway-JRC	19.4	**17.53**	**4.63**
Switzerland-JRC	14.6	**13.18**	**3.48**
UK-JRC	33.6	**30.35**	**8.01**
Observed Damages (Coverage and Risk Assessment Plan of Bistrița-Năsăud County, 2006)	**1.2**	**-**	**-**

In this light, we have analyzed and compared results calculated by the model (using the 7 curves proposed by JRC) to identify the effect of the applied depth–damage functions and quantify the effect of uncertainties associated with the modeling of flood damage. We have expressed the results in term of "function uncertainty" (Table 4), estimated by dividing each calculated damage value by the lowest calculated value; in our case the lowest value is the one calculated through the JRC functions for Netherlands, therefore, all the other estimated values were divided by this one. The values of this factor varies between 1.03 and 4.63 for all the functions, excepting the outlier value for JRC function for UK that is equal to 8.01, i.e. the difference between the highest and lowest damage estimates.

This results are consistent with other research in the field, as the study by de Moel & Aerts (2011) who found a factor of 5-6 regarding the function uncertainty, the study by Cammerer et al., (2013), who found a factor of 2.3 when the models are properly validated, the study by Jongman et al., (2012), who analyzed two study areas finding a factor of 3.7 and one of 10.5, and finally, Scorzini & Frank (2015) in which this factor varies between 1.1 and 14.8.

The presented results showed that the transferability of damage functions in space represent a gap in flood risk assessment and can lead to great uncertainty and, hence, the need of expressing the uncertainty but also to reduce it, by establishing a coherent framework for the data collection and evaluation.

6. CONCLUSIONS

In this paper a quantitative approach for flood damage assessment is presented. The aim is to create a more comprehensive methodology that includes all flood risk factors in the analysis and in this way offers a better understanding of the risks that can occur and can help in the decision-making process.

Furthermore, the quantitative economic damages estimation can be used in flood risk estimation, if there are used more flood hazard scenarios. This study is guided by the need for the development of new methods and tools that can support efficiently and efficacy stakeholders in their compliance with the Flood Directive2007/60/EC. In particular, this approach could be the initial step to develop a rationale procedure to reach objective results on which stakeholder can take decisions for prioritizing investments performing cost-benefit analysis of mitigation alternatives.

Moreover, the attempts in the last years to develop pan-Europeans damage models require more knowledge and more attention on the uncertainties regarding these models. Damage estimates are influenced by many factors, first in the process being the input data. Therefore, a homogeneous database across Europe is needed. Another important factor is the shape of depth-damage functions which can lead to great uncertainties.

The aim of this paper was to perform an uncertainty analysis using the damage functions of Huizinga, (2007). It was found that more attention should be given on the shape of depth-damage functions used at EU level; these ones having a large effect on the damage results. The calculated damages for the Ilișua catchment have a relative error which range from 37% to 300%, all the values being larger than the reported ones. The function uncertainty factor obtained varies between 1.03 and 4.63. This variation on the results can be attributed to the shape of the functions and the data used for the construction of this functions like synthetic or empirical and the inclusion of emergency service or stock costs or not.

Our results show that overall applicability and transferability of depth-damage curves to other geographical regions is still a major gap in current flood damage modeling, but the quantification of the uncertainties and its communication to stakeholders are the first step for the maximization of quantitative risk approach effectiveness, towards flood risk management objectives of the Flood Directive, ensuring that risk information is robust, credible and transparent.

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