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Water depth-damage functions for flood direct tangible damage evaluation in built-up areas in Sardinia (Italy)

S. Frongia*, A. Ruiu and G.M. Sechi
DICAAR – Dept. of Civil and Environmental Engineering and Architecture, University of Cagliari, Italy
* *e-mail: frongiasara@tiscali.it*

Abstract: Flash floods occurring in the Mediterranean area lead to investigate on relevant damages caused by floods in Sardinian territory (Italy). The Flood Directive 2007/60/EC, requiring a cost-benefit analysis for the definition of mitigation measures, should be supported by appraisals of flood damages. Actual study background recognises the use of water depth-damage functions as key elements in decision-making evaluation of authorities. Flood damage functions are still not available for Italy and should be developed considering the regional territory. This paper revises the Joint Research Centre Model approach (Huizinga H.J., 2007) for Sardinian region and provides water depth-damage functions for direct tangible damage assessment. Historical data on flood damages were collected considering two recent events. The first event occurred the 22nd October 2008 in Capoterra town, in the South-East of the region, where it caused damages in structures of residential and touristic area for millions of Euros, and 4 victims; the second event occurred the 18th November 2013 in the North-East area determining damages in multi-storey buildings in Olbia town and 13 victims. The collected data were statistically studied considering the possibility of fitting relations between water depth and expected damage data using a Pearson III probability distribution. The water depth-damage functions show different trends due to building types in the two studied areas. The procedure was subsequently implemented considering synthetically generated flood events in order to estimate the expected mean annual damage values due to flooding in prone areas and to verify economic efficiency of planned mitigation measures.

Key words: Water depth-damage functions, flood damage estimation, Pearson III probability distribution, JRC Model validation

1. INTRODUCTION

Modelling the flood damages in quantitative economic terms is a field of study currently under development and improvement by researchers as essential requirement defining mitigation measures. Methodologies and software for the appraisal of losses in human, property, financial, and social impacts caused by natural hazards have been recently developed (Scawthorn et al., 2006). Among them reaserchers are mainly working using HAZUS-MH, FLEMO Model, Damage Scanner, Flemish Model, Multi Coloured Manual, Rhine Atlas and Joint Research Centre Model (Jongman et al., 2012; MCM Model, 2005; Huizinga, 2007).

Usually, in the bibliography, the categorisation of damage is divided in the two classes of tangible and intangible damage, when the losses can or not be economically quantifiable and, subsequently, each class is divided in direct and indirect damage when the loss is respectively caused or not by a direct contact with the flood flow. The present work is focused on the evaluation of the direct component of the tangible flood damage by applying the water-depth damage approach achieved in the Joint Research Centre report: JRC Model (Huizinga, 2007). The main aim of the research is the identification of the economic amount of flood losses caused by the contact of the water with elements distributed in the territory. In fact, quantification of losses under existing conditions is valuable for understanding and communicating the importance of hazards and determining factors contributing to the risk (Scawthorn et al. 2006). The evaluation of flood damage in quantitative economic terms is a relevant issue assuming decision for stakeholders and government authorities who take advantages of these studies to optimize allocation of financial resources.

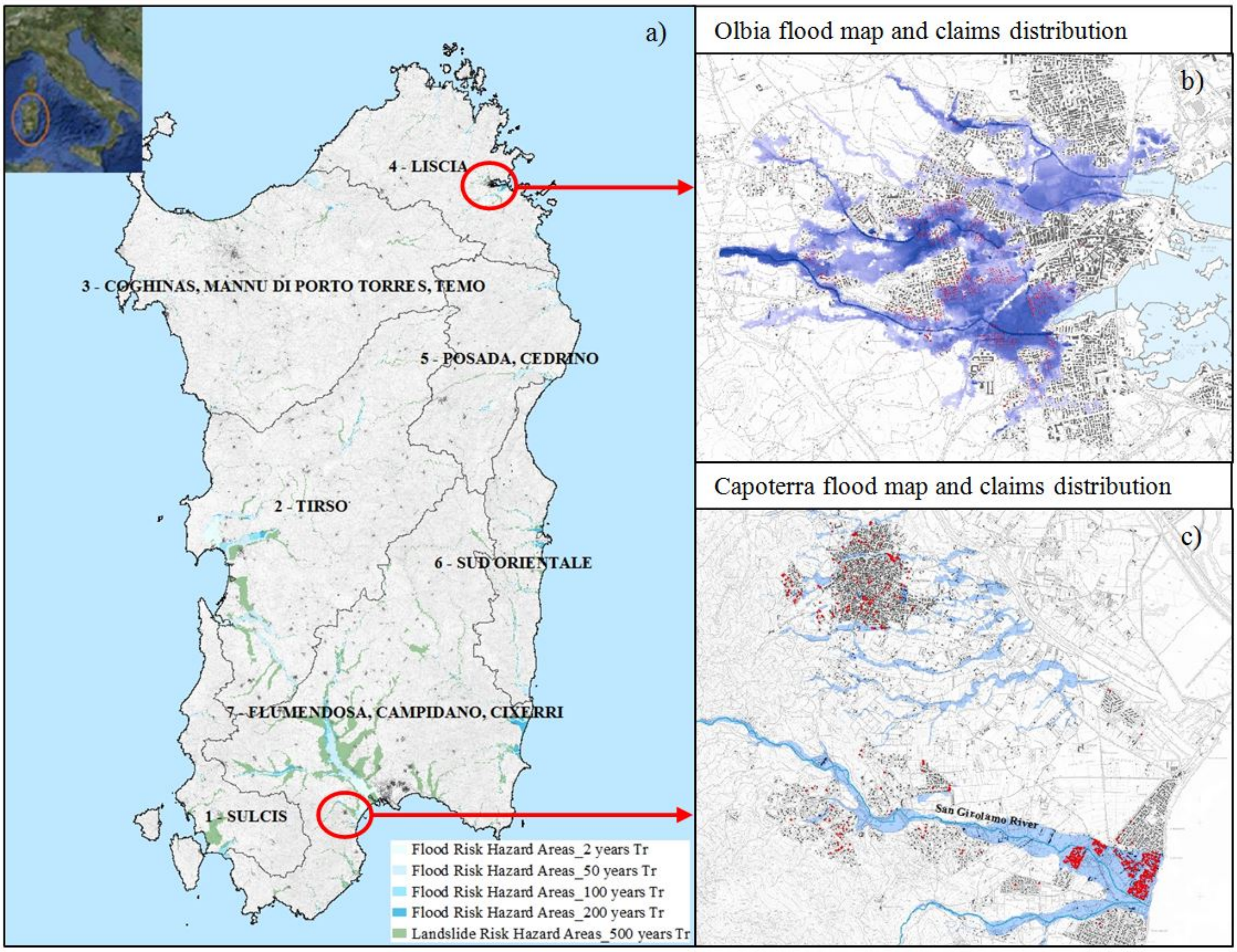

Figure 1. a) Location of Olbia and Capoterra council territory and hydrogeological risk areas defined in the Regional Flood Plan PSFF; b)Flood map of the 19th November 2013 event in Olbia and damage claims distribution; c)Flood map of the 22nd October 2008 event in Capoterra and damage claims distribution

The peculiarities, arose studying locally the territory to determine regional water depth-damage curves, lead to collect and analyse the database of refunds claimed after significant floods registered in Sardinia (Italy) in October 2008 and November 2013. The research examined two different urbanised areas, aiming to obtain regional representative water depth-damage functions and to allow a comparison with the JRC water depth-damage function for residential land use territories. The two study-cases are localised along the Eastern coast of the Sardinian region, as it is possible to observe in Figure 1a. Olbia town residential losses, in the North-East coast, are mainly related to multi-storey buildings, while Capoterra residential dwellings are mainly family houses of one or two floors located in the South-East of the Sardinian coast.

The available damage-claims database have been analysed taking into account uncertainties related with potential errors in data collection, limitations on water depth information and on building/inventory conditions. As a first step, results obtaining water depth-damage functions have been compared with the JRC curve and give back differences mainly due to the structural dwelling typologies. Subsequently, the research considers synthetically generated flood events in order to estimate uncertainty and reliability in the damage evaluations considering mean values of the damage in flood prone areas. This second step evaluation has been developed considering a Pearson III probability distribution to fit observed damage values.

2. WATER DEPTH-DAMAGE CURVE EVALUATION FOR THE SARDINIAN TERRITORY

2.1 Methodology elaboration and applicability on the Sardinian territory

The starting point in analysing potential flood losses is the quantification of the flood hazard using hydraulic models (Scawthorn et al., 2006; Frongia et al., 2015; Appelbaum, 1985; Smith, 1994; Pistrika and Jonkman, 2010; Tsakiris, 2014). This information makes aware of the potential extension of the flood and, consequently, of the values of the hydraulic parameters involved in the flood damage evaluation modelling. The approach here used for Sardinian territories appraises the magnitude of the damages caused by a flood relating water depths to flood losses. Usually, the losses, expressed in €/m^2, increase proportionally with the water depth and reach the maximum value of damage at a predefined water level. The behaviour of the damage associated to flood water depth changes in function of the land use category under analysis.

Mainly, we refer to JRC Model approach (Huizinga, 2007) that considers the territory organised in five land use categories (residential, commercial, industry, road network and agriculture). Accurated studies on water depth-damage curves have been already developed in some European Country and allowed Huizinga H.J. to define "harmonised" water depth-damage curves theoretically applicable to the whole European territory making available a general process for the flood damage evaluation. JRC Model considers the economic situation of the Countries to appreciate the maximum damage value caused by a maximum flood level of 6 metres. Nevertheless, studies undertaken to obtain the "harmonized" curves show a high difference between the values collected by each country: these aspects underline the necessity to validate the JRC functions country by country and, possibly, more deeply, at meso-scale level of regional territory.

The analysis in the present research considers collected data of damages caused by floods on residential territory in Sardinian region (Italy). The evaluation of water depth-damage function takes advantages of the refund data collected by regional and council authorities after the flood events of the 22nd October 2008 that hit the territory of Capoterra town, and of the 18th November 2013 registered in the territory of Olbia town. Both of the floods have been caused by intense precipitation rainfell in short time and reaching in few hours 350 mm of rain, in Capoterra territory, and 440 mm in Olbia territory.

The flood event registered in Capoterra town, South-East of the Sardinian territory (Figure 1c), has been modelled with the 2D hydraulic model MIKE (RAS-Vol.1, 2015). The MIKE model allows to evaluate the water depth level registered mainly in the suburban areas close to the coast where the most part of the damages have been caused by the overflow of San Girolamo River. Capoterra council office made available a sample of residential refunds consisting in 758 damage records. Each damage record has been georeferenced and associated with the relative built area acquired by Capoterra council cadastral map after a crosschecking process with the Google Street tool. Subsequently an accurate check process on data, the record number in the sample decreases to 329 records. The database clean-up was checked on the association of claim data with flood map. Mainly data refusal depends on lack of information of water depths that are not available everywhere in the flooded area. In some cases the required damage values were evaluated too high according with dwelling typology and refund limits. Figure 1c shows that the area where the flood has been localized: along San Girolamo River close to the coast.

The damages registered in Olbia territory after the flood of the 18th November 2013 have been provided by the Sardinian Civil Protection and by the Olbia Council office that supplied also the reconstruction of the flood map modelled with the 2D hydraulic model FEST-RS (Mancini, 2014). The crosschecked of the two samples provided by the Sardinian Civil Protection and Olbia Council office led to consider 1325 records of claim localised inside the built area; buildings were identified using the cadastral map of Olbia. As in previous case, the Olbia residential claims have been related with the flood map obtained by the reconstruction of the flood event in order to associate at each claim data the maximum water depth occurred. As in the previous case, subsequently an accurate check process on data, the sample size decreased from 1325 to 989 data. Figure 1b shows claims distribution in the urbanized area of Olbia town and the flood map.

3. DATABASES STATISTICAL VALIDATION

Capoterra and Olbia claims database are characterised by data consisting in the economic evaluation of the damage, expressed in €/m^2, and the related water depth, expressed in metres. The two samples have been categorized in classes of water depth of 0.5 m and for each class the mean value of the damage and its standard deviation have been calculated. Starting from mean values of each class, for Capoterra the obtained water depth-damage curve is described by a linear trend till the water depth reaches 0.5 metres and follows a trend interpolated with a polynomial of 3rd degree, as shown in Figure 2. The behaviour of mean data of damage collected by the event registered in Olbia town is defined by a linear trend reaching 0.5 m of water depth and proceeds with an exponential trend. The Olbia water depth-damage curve is reported in Figure 2, as well as the JRC evaluated function for the Italian country.

Differences between these curves need some comments. Firstly, the dissimilarities are related to the maximum water depth value that for these flooding zones do not exceeded 3 metres. Moreover, the differences are related to different type of urbanization: Capoterra residential dwellings are mainly family houses located in the South-East of the Sardinian coast, the houses are one or two floor buildings and damages are consistent just starting from few decimetres of water depth. Olbia town residential losses, in the North-East coast, are mainly related to multi-storey buildings and damages become more and more significant, as the water depth is growing. The same behaviour can be shown from the JRC curve; grater values here evaluated can be related to intrinsic buildings values. Uncertainties related with the mean values evaluation of these economic damages can be significant.

These uncertainties can be related to different factors: above all to different economic values of buildings, moreover, to the appraise of the level of damages determined inside building (including inventories) and due to limitation considering only the water depth as hydraulic parameter representative of the flood to define the damage value. Further evaluations can also be done considering the sum of mean and standard deviation values of each sub-sample (Frongia et al., 2015).

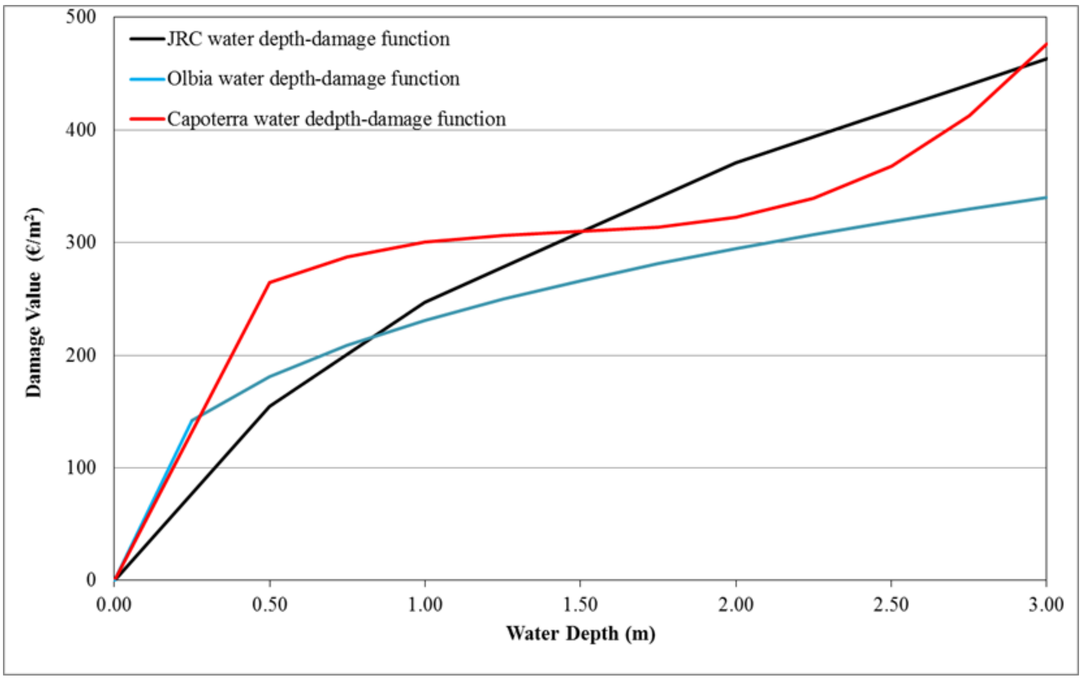

Figure 2. JRC, Capoterra and Olbia water depth-damage functions for residential territory

Here, in a deeper analysis, a statistical study has been focused on fitting the occurrence probability of the damage inside each class of the depth-damage sample. Unfortunately, only the sample of damage claims provided by Olbia flood event has proper size to completely develop this kind of analysis.

The damage sample, inside each class of water depth, has been fitted considering a Pearson III probability distribution, also called Gamma probability distribution, given by the following Equation (1):

$$p(x \mid a,b) = \frac{1}{b^{\alpha}\Gamma(a)} x^{\alpha-1} e^{-\frac{x}{b}} \tag{1}$$

where: damages are $x \in [0,\infty)$, b is scale parameter and a shape parameter of the distribution and $\Gamma(a)$ is the Gamma function:

$$\Gamma(a) = \int_0^{\infty} e^{-t} t^{a-1} dt \tag{2}$$

After the test of fitness was positively achieved for each water depth class, a procedure of synthetically generation of damages due to flood events has been implemented. The observed vector of damage values has been examined using the *gamfit* function of the Matlab library to obtain the maximum likelihood estimates of the gamma distribution parameters and to achieve in the *parmhat* output. *Parmhat* output consists in a vector of two elements, a and b^{-1}, that are the Gamma probability distribution parameters for each class, as shown in Table 1.

Table 1. Pearson III parameters for Olbia sub-samples of damage values

	Olbia	
Steps of h (m)	**a**	**b^{-1}**
0.0 < h ≤ 0.5	1.2886	50.0154
0.5 < h ≤ 1.0	1.5310	69.9979
1.0 < h ≤ 1.5	1.8619	80.4843
1.5 < h ≤ 2.0	2.3337	75.8464

A Montecarlo generation process has been then implemented in a Matlab script. The procedure generates a random matrix of probability, $N \times M$ size, of damage values, inside the considered class. The N rows of the matrix are equal to the size of the observed values of each class; the M columns are equal to the number of randomly generated events inside each class, set here equal to 1000. Considering the a and b parameters obtained for each class and the randomly generated probability value p (0:1), the matrix of the synthetically generated damage was created with the Matlab *gaminv* function that works according with the inverse gamma probability function:

$$x = F^{-1}(p \mid a,b) = \{x : F(x \mid a,b) = p\} \tag{3}$$

Matlab *gaminv* function determines damage values for the generated matrix of probability values. For each class, the script calculates again the mean and the related standard deviation. Moreover, the *quantile* function estimates the damage values with exceedance probability of 2.5%, 25%, 50%, 75% and 97.5%. This investigation can be useful to define the reliability of the damage evaluations and related level of uncertainty. Obtained results are given in Figure 3 showing the quantile amplitude, growing with the water depth.

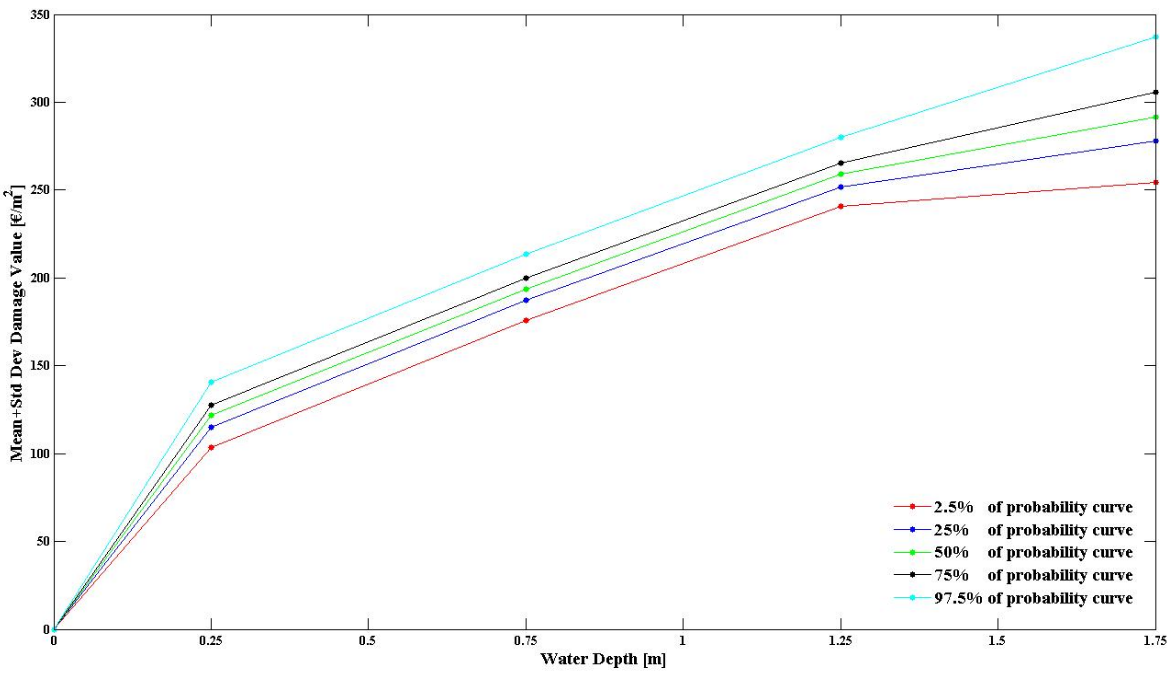

Figure 3. Curves of Olbia claim sample with probability to be exceeded at level of 2.5%, 25%, 50%, 75% and 97.5%

4. RESULTS AND CONCLUSIONS

The analysis here reported was developed with the aim of defining residential water depth-damage curves for Sardinian territory studying data collected after the floods happened in the urbanised areas of Capoterra and Olbia. Obtained results allowed a comparison with the residential water depth-damage curve proposed in the JRC Model. Nevertheless, JRC water depth-damage curves are the result of an harmonisation process of curves collected in several European Countries marked by a significant heterogeneity in building typologyes. The building typologyes are characterised many types of dwellings surely very different considering each country and territory peculiarityes and features. This aspect pinpoints the uncertainty in JRC possibility of application evaluating residential water depth-damage function.

The need to consider specific damage function has been investigated: Capoterra buildings in the suburban coastal area could be defined as villa one or two floor typology for which the most part of the damages are determined by low water depth; Olbia town dwellings are mainly many floor houses and block of flats lived by different families. This dissimilarity reflects differences on the trend of the water depth-damage curves. The difference with JRC evaluated function for the Italian country are significant and underline the necessity to develop specific curves for specific territories, even considering the only residential use.

More studies in depth have been done considering Olbia database to evaluate level of reliability in damage evaluations using this water-depth damage approach: a statistical procedure for uncertainty estimation level was developed by a Montecarlo generation, fitting frequencies in each water-depth class of damages by a Pearson III probability distribution.

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