Flood Damage Risk Assessment Optimizing a Flood Mitigation System

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Abstract: Flood risk management plan for potentially damaged areas is a main requirement from the European Directive 2007/60. Therefore, assessment and evaluation of the potential flood damages in quantitative terms need to be defined in mapped flood risk areas. Quantitative evaluation should be in agreement with the required cost-benefit analysis as a rational decision-making tool optimizing the flood mitigation system. In the first part of the paper, analyses are reported, based on recent flood events that had taken place in the Europe, in order to obtain depth-damage functions to apply in the Sardinia region (Italy). Flood damage functions are not still available for every European country and the paper analysed previous studies to define depth-damage functions for this region. The paper focuses then on the validation of the proposed depth-damage functions. The available flood data and reported damages of the massive storm happened in South-Est Sardinia the 22nd of October 2008 are analysed. Data analysis allows to compute the total economic losses for different land uses conditions and to compare with the evaluated ones. In the last part of the paper, expected damages evaluated using depth-damages functions are used for the Coghinas river lowlands valley. The regional Water District Authority defining the flood risk management plan considers this river basin as a pilot area. Applying hydraulic models to floodplain river flow allows evaluation of the expected flood damages using the depth-damage functions. Moreover, the procedure allows developing the cost-benefit analysis in order to justify different design scenarios and gives a rational decision-making tool optimizing the flood mitigation system

Key words: Flood Risk Management Plan • Flood Directive 2007/60 • Quantitative flood damage • Depth-Damage Function • Capoterra Flood 2008 • Coghinas river lowlands Valley •Sardinia

1. INTRODUCTION

The last two decades had been stage important European flood disasters that lead the European Commission up to find mitigation for these catastrophes. Currently, in the Mediterranean region the flash flooding is the most common type of inundation since the majority of flood events is induced by intense rainfall occurring in short time periods and reaching quickly impressive flow rate (Pistrika, 2014). In addition of the climate changes, the nowadays people moving from rural areas to cities increases the urbanization and subsequently an emergency or disaster management plan is necessary in terms of preparation, support and reconstruction when natural or man-made disasters occur (Vojinovic, 2008). The European Commission main outcome, to contrast the problem, is the Flood Directive 2007/60/EC. The Flood Directive requires focusing the attention on the assessment and management of flood risks. In Article 7 of the chapter IV in the Flood Directive, is highlighted that the "Flood Risk Management Plans shall take into account relevant aspects such as costs and benefits" (European Commission, 2007), while in the chapter III the European Commission had required the preparation of the flood hazards maps and the flood risk maps. The required flood maps allow to be conscious of the potential floodplain areas for the all European territory and the resulting depth maps are the launch pads to start the require economic damage assessment. The potential flood damages require a conversion in term of quantitative amount to give an idea of the order of the potential flood magnitude. At this step is placed the necessity to use a rational decision-making tool to evaluate the damage amount and the definition of specific mitigation systems. In a later stage, a costs-benefits analysis allows to define which of the available solution could be considered the best one in economic terms. A glance at the actual study background underlines the importance of the depth-damage functions as one of the element of the decision-making tool to evaluate the economic damage amount and help the stakeholders on financing decision (Pistrika, 2014).

In general terms, economic damage can be divided in four types: direct tangible damage (e.g. physical damage due to contact with water), indirect tangible damage (e.g. loss of production and income), direct intangible damage (e.g. loss of life) and indirect tangible damage(e.g. trauma) (Jongman 2012). In the "Comparative Flood Damage Model Assessment", B. Jongman et al. described seven available flood damage assessment models: FLEMO, Damage Scanner, Rhine Atlas, Flemish Model, Multi-coloured Manual (MCM), HAZUS-MH and the JRC Model. All of these models consider in their analysis only the flood direct tangible damage defined in function of the flood water depth. According with the majority, the most common hydraulic variable used to develop the flood-damage analysis is the water depth, although flooding is a complex process determined by a large number of hydrologic and socioeconomic factors (Jongman, 2012). The common method to estimate the direct tangible damage is the application of depth-damage functions (Smith, 1994). In this paper the JRC Model methodology is taken into consideration and it based the analysis on depth-damage functions. Italy is one of the European member states without own depth-damage functions, for this reason a data validation is necessary to confirm the JRC Model output for Italian basins. The achievement of this step has been developed analysing the catastrophe occurred in the South-East Sardinia territory the 22nd of October 2008. The validation has been developed, in particular, for evaluated economic damage of Capoterra Council territory, for the city centre and for the urban area nearby the coast damaged by the flooding of Rio San Girolamo and its attribute Rio Masone Ollastu. Finally the analysis had been applied for the pilot basin of the Sardinian Flood Risk Management Plan, the Coghinas river lowland valley. The flood risks mitigation procedure in the pilot basin was supported by hydraulic simulation of flood events considering three return periods (50, 100 and 200 years) and was developed with HEC-RAS 4.1 software (USACE). The floodplain has been described also in terms of land use considering the Corine Land Cover maps with some changes properly developed for Sardinia territory.

2. FLOOD DAMAGE ASSESSMENT METHODOLOGY

The present work mainly takes under exam and applies the JRC Model, developed by H.J. Huizinga (2007), commissioned by the European Joint Research Centre. The available flood damage assessment model can be classified for three main aspects: scale, input hydrological data and damage calculation. The scale of application used in the JRC Model defers among Regional, National and European scale based on the studied case in the whole European area. Other models, as the MCM of the Middlesex University, work on local scale, taking in consideration the different type of scale of application shown so far (Jongman, 2012) (Messner, 2007). The types of water depth data available are divided into synthetic and empirical data.

The several recent floods lead researchers to analyse hydrological data collected during site inspections immediately after the flood event, but at the same time also synthetic data from "what-if" analysis of a simulated potential flood are still used (Jongman, 2012). JRC Model flood damage assessment considered both type of input data: empirical and synthetic. Although the hydrological data taken in consideration for the analysis is the water depths, other important factors should be used, mainly: flow rate, water velocity, flood duration, as determining damages on the flood prone areas. In the JRC approach, the damage calculation depends on depth-damage function used (absolute or relative), and the type of land uses. Absolute depth-damage function considers monetary losses determined by water depths, while the relative depth-damage function represents the percentage of the losses in respect to a pre-defined maximum damage value. Two types of costs are usually taken into consideration for the economic analysis: replacement and depreciated values. The JRC Model summarises different studies developed by the European countries achieving harmonized curves to fit the whole European area. Collected damage values can vary largely between the countries, so all of them had to be verified and, eventually, adjusted. The depth-damage functions allow determining the relative depth-damage curves by considering a directly proportional between a flood damage coefficient and the water depth.

Moreover, the JRC Model subdivides the territory in five macro categories of land use: Residential buildings, Commerce, Industry, Roads and Agriculture. Thus, the analysis had been realised for five depth-damage harmonised functions, one for each land-use macro category according with the CLC2000 and Moland dataset (H. Huizinga 2007). Maximum damage values could be evaluated on the base of the Gross Domestic Product per Capita PPS for each European country. The obtained data for Italian country are given in *Table* 1.

Table 1. Maximum Damage Values per damage category for Italy (from Huizinga, 2007 table 2-13)

Land use category	**Maximum Damage Value (€/m2)**
1.Residential Buildings	618
2..Commerce	511
3.Industry	440
4.Roads	20
5.Agriculture	0.63

In this work some changes took place relating to this methodology in terms of land use and depth-damage curves definition. The land use maps have been evaluated considering the CLC2003 and updated to take into account particular characteristics of Sardinia territory. The changes are based on details observed trough digital orthophotos of the 2006 and 2008, digital orthophotos AGEA 2003, Ikonos 2005/6 images and others sources (ARDIS, 2014). The update allows to verify the actual hydrography boundaries, the roads and infrastructures, shore lines, and permit to identify mitigation system already built, weak points in the territory and in the existing structures. The land use database is conform to the CLC2003 but a deep study of the territory shows the necessity to improve the database with more information regarding Mediterranean protected vegetation areas, new built environmental areas with public or private buildings (e.g. a public primary school, upper school, hospitals or old age homes). The improved land use maps is characterised by 201 types of territorial elements. Afterwards land use updates, the five JRC Model macro categories have been increased to twelve. *Table **2*** attributes to each category the respective maximum damage values and diversifying them more in detail (e.g. in terms of type of roads, type of protected areas). The exam of the new land use category list emphasize as, unlike the JRC Model, the present work is not limited to compute the direct tangible flood-damages. The new framework can consider macro categories for which flooding can determine intangible damages. As shown in the *Table **2*** , the related economic maximum flood damage cannot be defined in an univocal manner, as for Environmental heritage areas or Historical heritage areas.

A second minor modification, relating to JRC Model, is to reduce the maximum range of the water depth: from six to five meters. The trend of flood damage curves is given in *Figure **1***. Moreover, in the following paragraph a validation procedure has bee developed on these depth damage curves considering real case analysis.

Table 2. Land use Categories and related Maximum Damage Value for Sardinia Region

Land use category	**Label**	**Maximum Damage Value (€/m2)**
1.Residential Buildings	R	618
2.Commercial	C	511
3.Industry	I	440
4. Agriculture	A	0.63
5.Council Roads	N	10
6.Provincial Roads	P	20
7.Other Roads	S	40
8.Infrastructural (Areas with water supply network, electricity grid and similar systems)	T	40
9.Dams, rivers and similar areas	H	0
10. Environmental heritage areas	J	0

Land use category	Label	Maximum Damage Value (€/m2)
11. Historical and archaeological heritage areas	K	0
12.Area subjected of other intangible damages	X	0

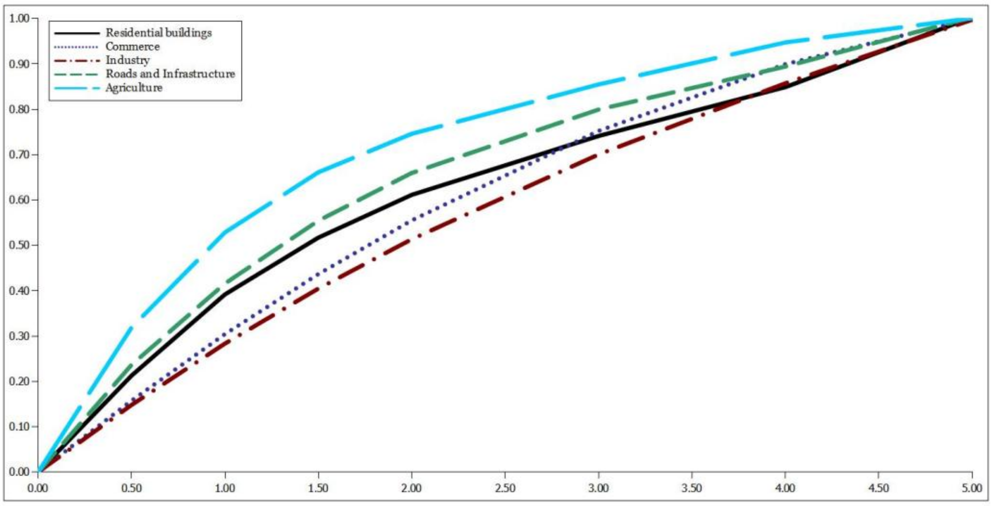

Figure 1. Flood Damage Approximate Harmonise Functions for EU Member States

3. CAPOTERRA FLOOD DATA ANALYSIS

As previously asserted the JRC flood damage assessment methodology requires a validation phase considering collected data from flood events to confirm its outcomes for different areas.

In October 2008 a massive storm hit Sardinia region and the worst damaged area has been, in particular, Capoterra town in the South-East of the Sardinia island. The town centre area, the urban area near and on the coast had been damaged by a massive rainfall, that reached 350 mm in less than 3 hours, and by the flooding of River San Gerolamo and its tributary, River Masone Ollastu. The biggest wave that hit the area reached a level around five meters, as reported on the simulation developed with MIKE21 published by the Hydrographic District Authority (ARDIS 2011). The collected data, obtained by Capoterra Council, describe the damage for the Residential and Commercial land use categories (RAS 2008) (RAS 2008). Furthermore the Agriculture data had been collected by the Sardinian Regional Division for Agriculture handout administration (ARGEA) (RAS 2008). The depth-damage curves validation required the georeferencing of the acquired damage data, the considering of the related land use category and defining for each data the highest recorded water depth for each damaged site. After crosses check on the data to verify if all the required information were available, the economic assessment has been started. The georeferencing work was confirmed overlaying the Regional Technical Map in scale of detail of 1:10000 meters (CTR maps that describe the territory) with the digital orthophoto of Capoterra territory, the land use map and the georeferenced collected data as shown in the the Figure 2.

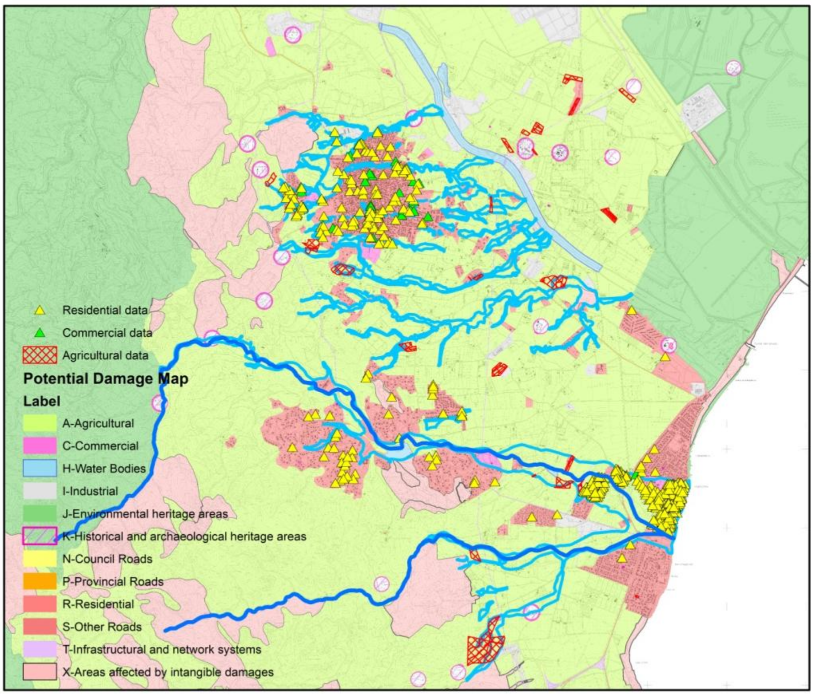

Figure 2. Residential, Commercial and Agricultural Capoterra collected data Georeferentiation and Land Use Map

The Residential and Commercial damages data have been cross checked with Google Street information and Capoterra cadastral shape file in order to confirm for each collected element the exactly building cadastral area and civic address. The same process involved the Agricultural data for which the cross-checked has been done with the proper cadastral shape file. Once that all the data had been cross checked and that gave back a positive result, the three available category samples have been submitted to statistical analysis.

At the first stage, the residential data have been analyzed considering the whole cadastral area related at each damage-data in order to find the representative specific damage in Euros per square meters. Residential building returns an appraisal damage of 11.53 Mln € for a damaged area equal to 507945.57 m^2. The statistical analysis on the sample gives back a maximum specific damage of 630.58 €/m^2 and a mean value of 40.78 €/m^2 .

In a second stage, the statistical analysis was re-applied because we considered an overestimation have been caused by a cadastral area too bigger than the real buildings area truly damaged. The analysis required an improvement in the procedure by calculating the built area of each residence. In the new analysis the evaluated total damage of 11.53 Mln € is coupled with a reduced damaged area of 165869.59 m^2. Maximum damage value raised to 1050.97 €/m^2 and mean damage value to117.97 €/m^2.

In a final stage we focussed to find the distribution of flood-damage in function of the related water depth, comparing results with the JRC depth-damage function for Residential buildings. **Hata! Başvuru kaynağı bulunamadı.** highlights differences between interpolation of our mean values and JRC curve. Considering the high level of data scattering, in the same Figure 3 also the means plus standard deviation are reported. Some other statistical analysis have been developed in order to give a statistical meaning to evaluated flood damages.

Analysis on Commercial and Agricultural area damages are not completely developed in this validation process due to the reduced amount of information on damages occurred in areas having this land uses

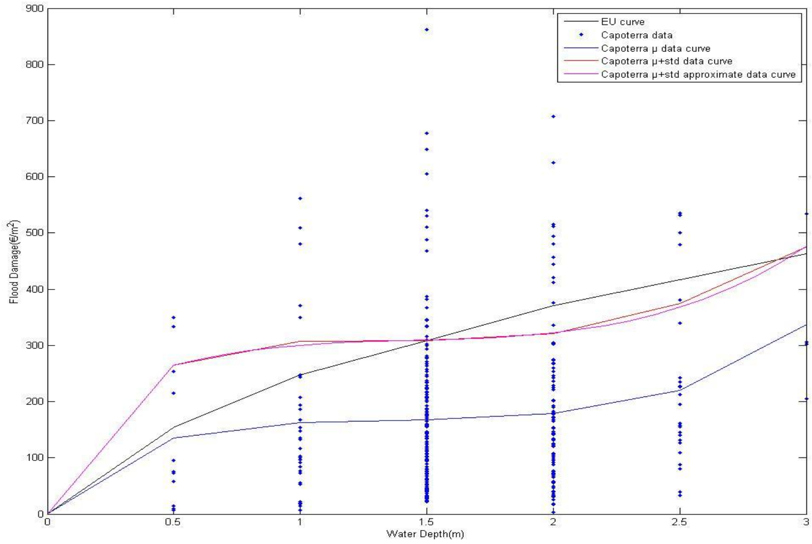

Figure 3. EU-JRC Residential use depth-damage curve and Capoterra collected damage data

The lack of economic studies developed on flood events for Sardinia territory have made the Capoterra collected data very useful to obtain proper flood-damage curves applicable for Sardinian flood-damage prone areas. As explained in the previous section, the collected data have been analysed in order to evaluate average values, modifying JRC outcomes for Italian territory. Results reliability depends on many factors as the quantity and the representative of used data in the analysis, area and environment characteristics, hydraulic measures and model accuracy, etc.. These reasons brought to focalise the attention on Residential building information in Capoterra data and leave aside the Commercial and Agricultural samples no sufficiently representative. Residential sample were characterised by 551 elements distributed in the city centre, suburban and coastal area with different types of buildings. The same way of thinking is not permitted for the Commercial and Agricultural samples. The shortage of data explained above and the analysis on commercial types (little local shops) make the Commercial and Agricultural samples unqualified to be analysed.

Residential building damage curve drafted considering mean values plus standard deviation is close to the JRC Model outcomes in its central values, considering a range of three meters depth. The plot of the data in Figure 3, confirm mean values close to the Residential damages obtained by JRC Model depth-damage curve. Moreover, we obtained higher gradient in damages values at lower depth values and at higher values, meanwhile the waited values remain about constant in a wide range of depth. Specifically, the analysis has been developed considering the sample divided in six water depth steps: 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 meters. The depth-damage function for Capoterra samples can be subdivided in three main trends. The curve is characterised by a steep increase up to 0.5 meters; it follows with a quasi-stationary tendency till 2.0 meters and arises a second steep increase from 2.0 meters to 3.0 meters.

Considering the specific damage actions by a flood in this area the obtained depth-damage curve should represents the process properly. The Capoterra buildings mainly consists in one or/and two floor houses for which the main damages to contents are determined at the ground floor where usually white goods and heating systems are located. Therefore a water depth of 0.5 meters, or even 1.0 meter, is the cause of the main non-structural flood damage related with primary goods, as also required in the Sardinia Regional Deliberations to admit the losses refund. When the water depth increases to more than 2.0 meters it can contribute to increase damages on structures of the residence reaching the roof or the first floor. For intermediate values the main flood damages have been beforehand determined and this justify the depth-damage quasi steady trend for intermediate values.

The depth-damage curve could be approximated with a polynomial of 3° degree that is rather stable with a small increase till 2.0 meters and then raises mildly to 3.0 meters exceeding slightly the JRC depth-damage function, as represented in Figure 3. The recommended depth-damage curve in order to consider not only direct damages is then the upper one in Figure 3, evaluated considering standard deviation added to mean values. Application of this gave back an estimation of potential damage of 17.39 Mln €, meanwhile the calculated damage by JRC methodology was 22.56 Mln € for the considered area.

4. DEPTH-DAMAGE FUNCTIONS APPLICATION AND RESULTS: COGHINAS RIVER LOWLAND VALLEY

The Coghinas river basin lowland valley has been stage of the Flood Risk Management Plan (FRMP) methodology development, as considered pilot basin for Sardinia Region Administration.

The pilot basin is located in the North-East coast of the Sardinia island and can give application for flood damages curves application. In this pilot basin residential, commercial, industrial and different types of roads and infrastructures and the agricultural categories are located. As defined in the second chapter of this paper, the land use categories have been modified by five groups, of the JRC Model *Table* 1, to twelve groups according with Sardinian territory characteristics, *Table **2***. The twelve land use categories are suitable to describe the four types of damages, defined in the first chapter, but only the direct tangible damage is computed in this paper and the maximum damage value is defined for eight land use categories while for the remainder categories the maximum damage value assigned is 0 €/m^2 (*Table **2***).

The Sardinian Flood Risk Management Plan considers the previous hydraulic simulation developed in Sardinia hydraulic plans, the Hydro-geological System Plan (PAI) and especially the Fluvial-Zones Definition Plan (PSFF) (RAS, 2008) (RAS, 2013), both plan considered with the related updates after their first publications. The attention was focused on the PSFF Coghinas river lowland valley simulations mainly considering the hydrologic, hydraulic and geomorphological analysis for critical return periods of 50, 100 and 200 years.

The Sardinia Geoportal, making available the Digital Terrain Model (DTM) with a grid resolution of one meter, gives the opportunity to run the hydraulic simulations with availability of detailed cross sections attaining floodplains with high details on flooded areas and related water depths. The hydraulic simulation has been developed using the one-dimensional software package HEC-RAS 4.1 of the Hydrologic Engineering Centre of the US Army Corps of Engineers, (USACE 2010). Modelling inundation areas allow to evaluate water depths in a grid of three meters side, thanks to availability of DTM.

Consequently, it was possible to set up the GIS maps to reach all the necessary data for the JRC methodology application. This step was developed with ArcGIS software. The obtained data set was characterised by a grid-code of water depth defined for each cell of nine meter square. Meanwhile, the land use shape file was defined by polygon with land use characteristics, land use label and the related maximum damage value for each land use macro category. At this point a specific computation code compute the flood damage coefficient, α, for each cell according with the relative depth-damage curve. For each cell the flood damage coefficient was elaborated coupling it with the cell area and the maximum damage values assigned, in this way the potential flood damage for every element has been obtained. The returned values of each scenario are shown in the *Table **3*** and the analysis shows that the appropriate basin has been chosen like pilot basin for the Flood Risk Management Plan. In fact, ten of the twelve land use categories have been analysed and for each category the respective flooded areas and related evaluate damaged are defined.

Considering floodplains, shown in the Figure 4 related to scenarios with return periods of 50,100 and 200 years, the increases of the evaluated damage are justifiable by the fact that flood expansion hit residential areas nearby the towns and nearby the coast, for which the maximum damage value per square meters is 618 €.

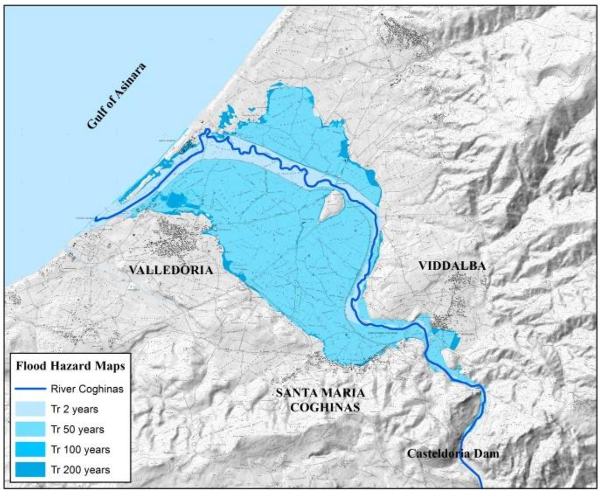

Figure 4. P.S.F.F. Flood Maps of the Coghinas river lowland valley sub-basin.

Table 3. Evaluated Potential Coghinas river lowland valley Damages and Areas

Label Land-Use Category	T_R 50		T_R 100		T_R 200	
	Area (m^2)	Damage (€)	Area (m^2)	Damage (€)	Area (m^2)	Damage (€)
A	13'055'381	5'221'925	13'219'059	5'688'986	13'319'222	6'019'251
C	41'021	7'581'223	41'969	9'107'924	42'396	10'304'961
I	53'292	7'193'880	70'330	9'150'344	73'184	10'950'897
J	2'075'232	-	2'099'058	-	2'119'113	-
K	22'310	-	26'687	-	40'014	-
N	42'576	168'716	45'321	204'835	45'786	232'406
P	99'089	802'391	104'138	979'904	111'261	1'137'800
R	114'945	23'916'273	135'434	31'182'354	148'135	37'856'384
T	213'333	3'497'885	217'036	4'054'690	220'499	4'504'593
X	634'887	-	656'570	-	673'836	-
Total	16'352'066	48'382'292	16'615'603	60'369'036	16'793'446	71'006'292

5. CONCLUSIONS

The results obtained in this study allow underlining the flood risk assessment in flood prone areas. Economic evaluation of flood damage risk is one of the most important topics under analysis in the world. The flood damage analysis considers the appreciation of the four type of damage identified so far. Nowadays the research on flood risk management is focused mainly on the economic evaluation of the direct tangible damage based for the majority on depth-damage curves in function of the main land uses and water depth data collected with empirical or synthetic methods. According with several researches the indirect tangible damage can be evaluated as percentage of the direct tangible damage considering how the area under analysis is exploited by the society, in other terms evaluating the percentage areas above the total area for each land use macro category identified in the territory. Notwithstanding the intangible damage is still under analysis. The flood intangible damage could be divided in two branches: direct and indirect damage. The direct intangible damage can be considers as loss of life caused by the flood event and a evaluation economic method can be an analysis on the flood insurance that see a recently increase (E.C. Penning-Rowsell 2014). While the indirect intangible flood damage can be the trauma determined by losses after flood events. For the flood indirect intangible damage is not defined a proper evaluation methodology but a statistical analysis of the potential psychological therapy and related costs could be considered as a start. Because of the uncertainty on the economic evaluation and the several methodology only the assessment linked with the flood direct tangible damage is the field mainly under studied. Focusing the attention on depth-damage curves, this paper is the outcome of a analysis of the methodology realised by H.J. Huizinga to obtain the harmonised JRC Models depth-damage curves applicable on the whole European territory.

Moreover, depth-damages had been under validation to verify the methodology for Sardinia region it in order to apply this procedure developing the Flood Risk Management Plan required from Flood Directive 2007/60/EC. In addition, the available collected data allowed to obtain new depth-damage curves proper for Sardinia territory, at least considering Residential depth-damage curve. Further investigations are still in progress considering other floods event recently occurred.

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