FLOOD VULNERABILITY USAGE FOR FLOOD RISK ASSESSMENT IN THE REPUBLIC OF MOLDOVA

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***Abstract**: Vulnerability is the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience. The most recent flood events in 2008 and 2010, occurred on the territory, demonstrated that the country is vulnerable to inundation. The concept of vulnerability covers three dimensions: social, economic, and environmental. In this paper the focus will be given on the economic dimension of the flood vulnerability. In the framework of the Management and Technical Assistance Support to Moldova Flood Protection Project a damage model was applied at a national scale using three land-use classes. Evaluation of economic damages has been performed using depth-damage curves for each land-use type. These depth-damage functions have been built taking into account data and functions found in literature and the particular characteristics of assets in Moldova.*

***Keywords:** flood risk, vulnerability, absolute damage curve, relative damage curve, Flood Directive.*

1. Introduction

The historic events of natural hazards on the Republic of Moldova territory was studied by Mihailescu [9]; the study confirms that floods on the Republic of Moldova occurred from the oldest times – the first documented events were in 544 AC, 545-547 AC, 895-896 AC, 1007 AC, 1146 AC,1156 AC, 1162 AC, 1164 AC etc. In the XXth century the flood events occurred in 1908, 1911, 1913, 1927, 1932, 1933, 1941, 1948, 1955, 1962, 1969, 1974, 1976, 1979-1981, 1984, 1991, 1993, 1994, 1995, and the most recently events occurred in 2008 and 2010 [1], [9]. But, actually, the risk is different from 544 AC to 1007 AC, from 1007 AC to 2008 AC, and differences permanently increase. Firstly, because vulnerability is the component that changes in the time and it depends directly on the level of economic development of the country. Secondly, vulnerability concept has a wide range of interpretations and dimensions along with multi definitions and different conceptual frameworks. Moreover, according to UNESCO-IHE [14] the vulnerability definition has changed significantly over the last 20 years. The Programme on Prevention, Preparedness and Response to man-made and natural Disasters (PPRD East) defines vulnerability as the physical, social, economic and environmental factor or process which increases the susceptibility of a community to the impact of hazards. UNESCO-IHE in its study on Flood Vulnerability index considers that vulnerability is the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience. The vulnerability equation is [14] **Vulnerability = Exposure + Susceptibility – Resilience.** From the wide range of studies on vulnerability, it can be concluded that its concept covers three dimensions as social vulnerability, economic vulnerability and environmental vulnerability. In this paper the focus will be given on the economic dimension of the flood vulnerability.

2. Background

As the Republic of Moldova has two transboundary rivers, Prut and Nistru, both the flood vulnerability and flood risk assessment should be analysed and studied together with the neighbouring countries: Romania and Ukraine. Romania, as an European Union (EU) country, is obliged to implement the Directives in the field of floods and water related issues: Water Framework Directive 2000/60/EC and Flood Directive 2007/60/EC. The common policy of the EU is not only limited in activities within the boundary of the Union, but even to support and encourage the neighbouring non-EU countries in order to improve the resilience level for coping with flood disasters. The external actions of the EU have four key aims: supporting the stability, promoting the human rights and democracy, seeking to spread prosperity, and supporting the enforcement of the rule of law and good governance. One of the regional policies is the European Neighbourhood Policy (ENP) where the Republic of Moldova is one of the key partners. Policies and good practices from EU-countries are transferred to non-EU countries (as the Republic of Moldova) through projects, trainings, knowledge and technical exchange. In the field of flood vulnerability there have been implemented several projects financed by EU, such as: Prevention and flood protection in Siret and Prut - EAST AVERT (2013 - on-going), Consolidation of the functionality of hydrotechnical complex Costeşti-Stanca (2013-2015) under the coordination of the previous project, the mentioned Management and Technical Assistance Support to Moldova Flood protection Project (2013-2016) [1] and the PPRD East (2011-2014 Phase I, 2014-on-going Phase II). Besides EU, there are several international organisations that give support in the same field; one of the most active is the World Bank (WB). In the project Post Disaster Needs Assessment (2011) the funds were given by the EU, United Nations (UN) and WB; in the project Reducing vulnerability to extreme floods and climate change in Dniester Basin (2011-on-going) the funds were given by the United Nations Environment Programme (UNEP), the United Nations Economic Commission for Europe UNECE and the Organization for Security and Co-operation in Europe (OSCE); and, finally, in the project Disaster and Climate Risk Management (2011-2015) the funds were given by the WB. The gained experience helps the communities of the Republic of Moldova to be less vulnerable and to act properly in case of flood disaster

3. Research methodology

Under the Management and Technical Assistance Support to Moldova Flood Protection Project [1], the methodology for the evaluation of economic damages has been performed using depth-damage curves. This is the internationally accepted and most common method for the estimation of direct flood damage: this model is widely being used as a basis for investment and planning decisions. Depth–damage functions represent relationships between flood depth and the resulting monetary damage. For a given flood depth the function gives expected losses to a specific property or land-use type, either as a percentage of a pre-defined asset value (relative function) or directly in financial terms (absolute function). The study of these models were carried out by Smith, 1994 [13]; Kelman and Spence, 2004 [5]. There is a wide variety of flood damage models internationally used, differing substantially in their approaches and economic estimates. Some models that can be found in literature value assets at replacement costs (i.e. the estimated new value of the object or class), other are based on depreciated values (i.e. an estimate of the present-day cost of replacement or reparation). Replacement values are interesting from an insurance perspective, since they provide information on the potential pay-outs involved. On the other hand, depreciated values are an estimated factor of 2 lower than replacement values (e.g. ICPR, 1998 [4]) that gives a better indication of the true economic costs associated with the (partial) loss of the asset (e.g. Penning-Rowsell et al., 2010) [10]. Several analyses have been performed comparing the results obtained with different damage models (ICPR 2001 [3]; Kok et al. 2005 [8], Scorzini and Frank 2015 [12]) in order to tailor the model to the national level conditions. The comparisons, using a GIS based procedure, show that the model outcomes are very sensitive to uncertainty in both vulnerability (i.e. depth–damage functions) and exposure (i.e. asset values), and it is essential to adjust depth–damage functions to the particular characteristics of the assets exposed to risks and to adjust the asset values to the regional or national economic situation. Examples of relative damage curves, both empirically based on flood damage databases and/or on expert judgment, can be found in Germany with Rhine Atlas, Hydrotec and FLEMO models (ICPR 2001[3]), in the Netherlands with the Dutch Standard Method (Kok et al. 2005 [8]) and Damage Scanner (Klijn et al. 2007 [6]) or in the USA with HAZUS-MH (Scawthorn et al. 2006 [11]). Other curves have been developed by the JRC (HKV Consultants 2007 [2]) for different European countries based on historical data and literature review of existing studies (Fig. 1).

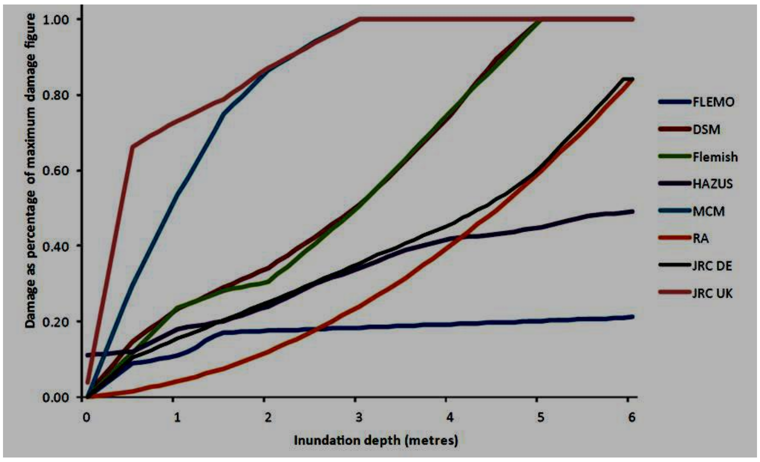

Fig. 1. Urbanised area depth–damage functions, from different studies

Considering that the model was applied at a national scale, aggregated land-use classes have been used. In particular three land-use classes have been used (residential urbanised area, non-residential urbanised area, agriculture) rather than considering individual objects (i.e. individual buildings). For each land-use type a different maximum amount of possible damage and a different damage function have been used. These depth-damage functions have been built taking into account data and functions found in literature and the particular characteristics of assets in the Republic of Moldova as explained in the following sections.

<u>Residential area</u>

The depth-damage function for residential areas used in the Management and Technical Assistance Support to Moldova Flood Protection Project is based on damage data of the Commissie Watersnood Maas provided for assessing damage in the floodplain of the Meuse River (in Kok, 2001 [7]). Two types of damages for residential buildings have been considered: the house itself and the content of the house (Fig. 2).

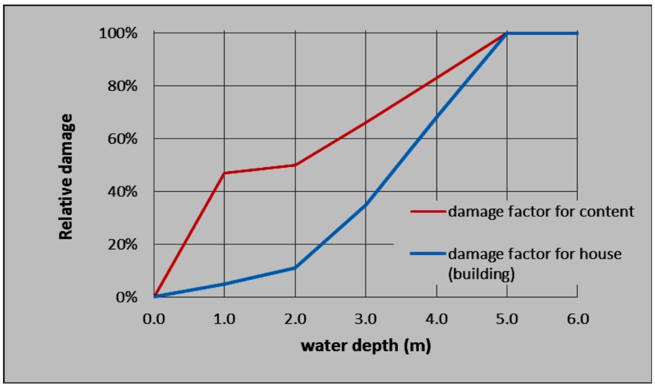

Fig. 2. Relative damage curve for the house itself and the content of the house (from Kok, 2001 [7])

For the residential urbanised area three different absolute damage-depth functions have been used. One for the villages (e.g. Albița, Ocnița, Pitești (Leova) etc.), one for the towns (e.g. Cantemir, Rîbnița, Taraclia, etc.) and one for the cities (e.g. Bălţi, Bender, Chișinău, Comrat, Tiraspol). These functions have been built using the same relative depth-damage function (Fig. 3) and different asset values as explained below.

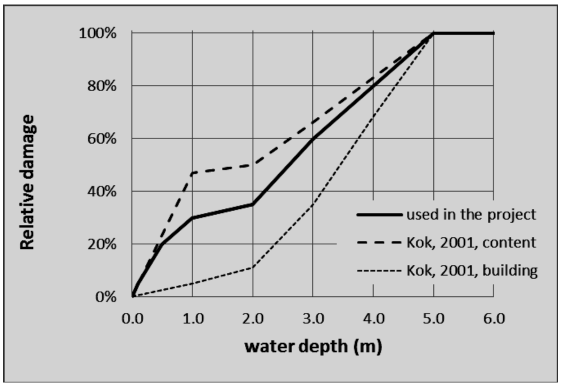

Fig. 3. Relative damage curve used for residential area, compared with Kok (2001) [7]

Villages. Buildings in Moldovan villages usually consist of individual one-story houses (more rarely two-story houses) generally with basements. The presence of the latter influences the shape of the depth-damage curve and, in particular, for the lowest water depths as even floods with small water depths can cause the complete flooding of the basement with great damages to goods and materials stored in it. On the basis of this consideration the relative depth-damage function has been assumed as in Fig. 3: this curve overlaps the relative damage curve for the content of a house for low depths of water, and then it assumes a trend located in the middle between the literature derived "content" and the "building" curves for increasing depths. The asset value for the residential urbanised areas in the villages has been calculated taking into account the average commercial cost of construction of a house (€ 5.000 - € 15.000, based on Moldovan real estate values), and the average density of houses in one hectare (around 10). In addition, considering that floods that have occurred in the past (2008 and 2010) showed that houses in the villages could be completely destroyed by flood, no reduction coefficient has been applied in order to evaluate the depreciated value of a house. Following the previous consideration an average value of maximum damage of 10 €/m² for the residential urbanised area has been assumed and the resulting absolute damage curve is shown in Fig. 4.

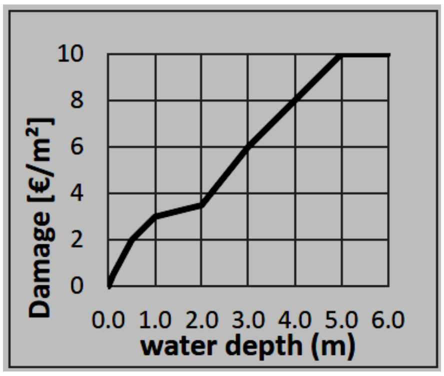

Fig. 4. Absolute damage curve for villages

Towns. Buildings in Moldovan towns usually consist of individual one-story/two-story houses, generally with basements, and in blocks (few in number) with apartments. In general, the principle described above for villages also finds application in this case, so the same relative damage curve was assumed (Fig. 3). The asset value for the residential urbanised areas in the towns has been calculated taking into account the average commercial cost of construction of a house (€ 25.000 - € 35.000, based on Moldovan real estate value), and the average density of houses in one hectare (around 12). For this reason a reduction coefficient of 0.5 has been applied in order to evaluate the depreciated value of a house. Following the previous consideration an average value of maximum damage of 17 €/m² for the residential urbanised area has been assumed and the resulting absolute damage curve is shown in Fig. 5.

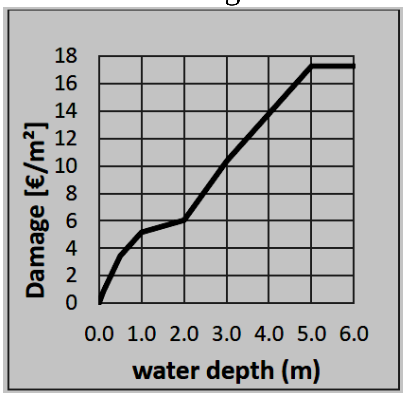

Fig. 5. Absolute damage curve for towns

Cities. In these urbanised areas buildings usually consist of individual houses up to 2/3 floors, and in blocks with apartments and business activity on the ground, sometime with basements. Even in this case due to the presence of goods and materials on the basement and on ground level, and due to the high presence of underground structures and infrastructure, it has been assumed that the relative damage curve is quite steep for the lowest depths of water and, for increasing water depths, assumes a trend located in the middle between the literature derived “content” and the “building” curves for increasing depths (Fig. 3). The asset has been calculated taking into account the average commercial cost of construction of a house (€ 60.000 - € 120.000, based on Moldovan real estate value), and the average density of houses in one hectare (around 13). It has been assumed that when a flood occurs in a city it is not able to completely destroy a house so, for this reason, a reduction coefficient of 0.5 has been applied in order to evaluate the depreciated value of a house. For the residential urbanised area has been assumed an average value of maximum damage of 52 €/m² which was representing in absolute damage curve (Fig. 6).

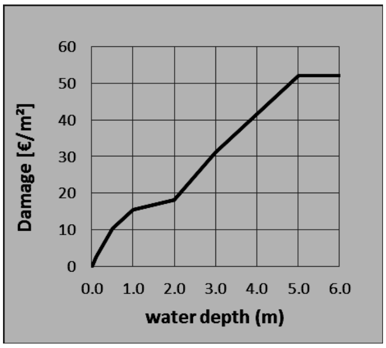

Fig. 6. Absolute damage curve for cities

Non-Residential area

The non-residential urbanised areas have been divided into industrial built-up areas and agricultural built-up areas. The first represents industries, commercial areas for the production of goods and so on. The second represent the areas for storage of agricultural machinery, goods and harvests. It is more difficult to assume damage functions for industrial areas because of the lack of damage data from past flood events and the greater variability; the value of the content could be much more than the value of the building. For the non-residential urbanized area a unique relative damage-depth function has been used (Fig. 7).

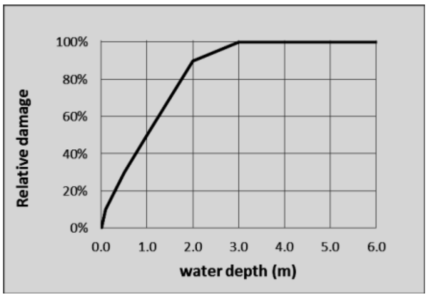

Fig. 7. Relative damage curve for non-residential urbanised area (from Kok, 2001)

The trend of the curve is very steep because all the goods, the harvests, the materials and the machinery are located at ground level; for this reason the losses reach 100% within a few meters of water. The asset value for the non-residential urbanised areas (industrial) has been assumed equal to the residential urbanised areas (cities): an average value of maximum damage of 52 €/m² for the non-residential urbanised area (industrial) has been assumed and the resulting absolute damage curve is shown in Fig. 8. The asset value for the non-residential urbanised areas (agricultural) has been obtained by multiplying the asset value of the residential urbanised areas (cities) by a factor of 1/8: an average value of maximum damage of 6.5 €/m² for the non-residential urbanised area (agricultural) has been assumed and the resulting absolute damage curve is shown in Fig. 8.

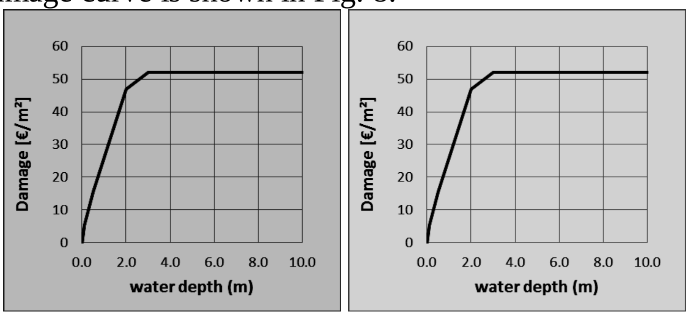

Fig. 8. Absolute damage curve for non-residential urbanised area (industrial, agricultural)

Agricultural area

As the most widespread type of crops in the Moldova floodplains are wheat and barley, a unique depth-damages function representatives of those crops has been used. The relative damage curve has a very steep slope because it has been assumed that only few centimetres of water will not cause any losses, and 1 m of water could cause the entire loss of the harvest. This, of course, is valid if the flood event occurs during the growing season. Considering that the major floods in Moldova occurred in the period May-August, this assumption is valid. The asset value for the agricultural areas has been based on the value of the normal costs of agricultural products for the year 2014. On the basis of this information it has been possible to evaluate an average value of damage of 0.06 €/m² for the agricultural area and the resulting absolute damage curve is shown in Fig. 9.

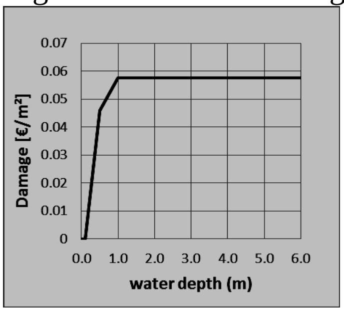

Fig. 9. Absolute damage curve for agricultural area

Once obtained the above described flood damage curves, a GIS based procedure has been applied for the calculation and mapping of the risk (Fig. 10): the flooded area (FA) is intersected with the urbanised area (UA) to obtain the polygon UA∩FA (the polygon consists of different triangular cells (hydraulic model mesh) and three different types of urban areas, each with a different damage function; for each triangular cell of UA∩FA the damage value (€/m²) is calculated applying the relevant damage function for the particular urbanised area to the maximum water depth (wd_i) in the cell as calculated by the hydraulic model; the damage for each residential area in the grid square [€] is calculated summing the product of the above value and the extent of the triangular cell.

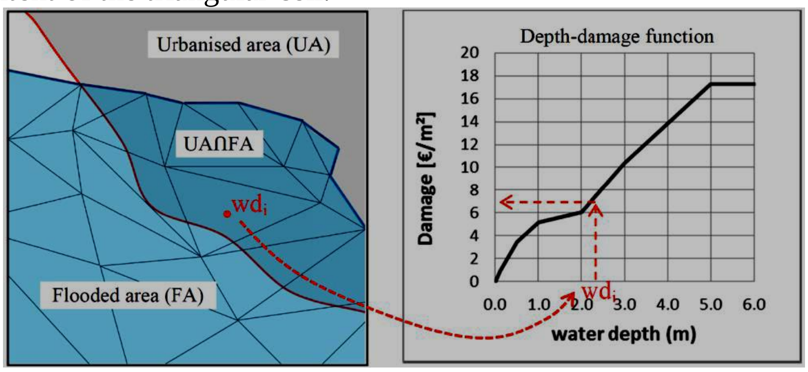

Fig. 10. Calculation of damages for residential area

After having estimated the values of the risk indicators for each flood return period, each flood risk indicator was "annualised" to estimate the long term annual average impacts. Finally a unique value of "total risk" was calculated, adding together the weighted annualised values of flood risk indicators. The final value of "total risk" is express in €. It is important to point out that the three previous indicators are only a part of the indicators composing the total risk assessed in the project.

4. Conclusions

This paper describes the flood vulnerability usage for flood risk assessment in the Republic of Moldova (RM). In particular the paper is focused on the evaluation of economic damages using depth-damage curves for each land-use type. These depth-damage functions have been built taking into account data and functions found in literature and the particular characteristics of assets in RM. The economic flood vulnerability increases with the water depth, and it is described by the depth-damage functions: both the residential urbanised area and non-residential urbanised area are seriously vulnerable when water depth is 2 m or more. The difference is on the assets exposed to the flood risk and on the type of area involved as residential (villages, towns, cities), industrial or agricultural. It has been assumed that for agricultural areas only 1 m of water depth could cause the 100% loss of the harvest, and this is applied assuming that the main floods occur in the period May-August. The obtained damage value, €/m², for each type of area allowed to calculate the economic vulnerability for each of them at the national level. So, the average annual amount of direct economic damages is about 27 M€. The annual direct economic damage for residential areas has been estimated 13,4 M€, for non-residential areas 11,7 M€ and for agriculture areas 1,6 M€.

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