Free and Open Source Software for Geospatial (FOSS4G) Conference Proceedings

Volume 18 *Guimarães, Portugal* Article 4

2018

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Hydraulic modeling for the assessment of flood hazard using the Iber software in the Amarante urban center

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Abstract: Recently, there is an availability increase of hydraulic modeling software that allows the analysis and definition of several hydraulic variables, namely water depth and flow velocity, which are important parameters for the assessment and management of flood-prone areas. The growing use of this software is related with the fact of being Free and Open Source Software (FOSS), making possible the understanding of different approaches and providing most reliable and accurate results of flood-prone areas according different return periods.

In this study it was used the freely hydraulic software Iber, a tool for two-dimensional modeling of water flow in rivers and estuaries that provides the hydraulic variables (water depth and velocity) required for the definition of flooded areas.

The main objective of this work was the analysis of flood hazard at the city of Amarante (North of Portugal), a place frequently affected by these extreme events. Due to the huge concentration of activities and services along the flood-prone area, economic and social damages caused by floods in the historical and urban center of Amarante are very important. Therefore, hydraulic modeling of the flooded area was performed for different return periods (10, 100 and 500 years) using the Iber software.

The main results shows the maximum extent of the flood, the water depth and the flow velocity for a specific return period and also, a flood hazard map for the return period of 100 years.

This case study aims to contribute for a better management of flood risk, which is a challenge for competent authorities, namely the local civil protection, fireman's and municipality services.

1. Introduction

According to the European Environment Agency (2017) the frequency and intensity of extreme hydrological events in different regions of Europe is expected to increase. Therefore, measures are needed to prevent and mitigate their negative impacts. In this context, the European Union has approved the EU Floods Directive (2007/60/EC) for flood risk assessment and management with the aim of reducing the adverse consequences associated with floods in the European community. Thus, in a first phase the Member States were obliged to accomplish a preliminary flood risk assessment, followed by the development of

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flood hazard maps and flood risk maps, and finally, in the third phase, they should draw up flood risk management plans, focusing on prevention, protection and preparedness [UE, 2007].

To help accomplish these tasks, hydraulic modeling method must be applied to help the management of flood risk by simulating possible flood scenarios, determining the space-time evolution of some hydraulic variables allowing the reduction of negative consequences and supporting an appropriate spatial planning.

The mathematical modeling of the water flow predicts the hydraulic parameters, such as water depth and velocity by the resolution of numerical methods of certain equations, always being an approximation to the reality [Cea and Bladé, 2008]. Regarding this, we used the Iber software[1], which is a two-dimensional (2D) mathematical model, for the simulation of water flow in rivers and estuaries [Bladé *et al*., 2012].

Iber presents different calculation modules, such as the hydrodynamic module that determines the depth and the velocity of the water, also having a turbulence module and a sediment transport module, which give it additional capabilities [Bladé *et al*., 2012]. The hydrodynamic module, which is the basis of all the processes included in this tool, solves the 2D Shallow Water Equations.

However, the main objective of this study is to apply hydraulic modeling to the flooded area of the city of Amarante, which is frequently affected by floods, causing a big disturbance in the operation of the numerous activities that are concentrated along the city. Thus, using the Iber software it was possible to delimit flood-prone areas, determine the water depth and velocity for different return periods (10, 100 and 500 years), and also obtain a hazard map for the return period of 100 years.

2. Literature Review

Currently, as Bladé *et al*. [2012] defends, numerical models based on two-dimensional shallow water equations are the most commonly used in studies of fluvial and coastal dynamics, assessment of flood zones, and calculation of transport of sediments and pollutants. Hydraulic modeling applied to the study of floods is essential for the assessment and management of flooded areas and, consequently, for reducing the risks associated with these extreme events. In order to evaluate the dissemination of this software, it was made a survey on Scopus[2] and Web of Science[3] database about the papers that uses Iber by using the keywords "Iber AND floods" and "Iber modeling". This survey, made in June 2018, resulted in 29 articles where Iber software was used. Figure 1A shows by country, the spatial distribution of the analyzed areas by the flood modeling studies performed with the Iber software. The results show that most of the researches were done in Spanish territory, being also evident the predominance of the countries of Spanish language, such as Argentina, Costa Rica, Mexico and Peru. Figure 1B, highlights the increase of studies in the last years, most of them published between 2016 and 2017, being also important the evolution of online courses available that have been increasing, probably due to a higher demand.

[1] http://www.iberaula.es/
[2] https://www.scopus.com/
[3] http://apps.webofknowledge.com/

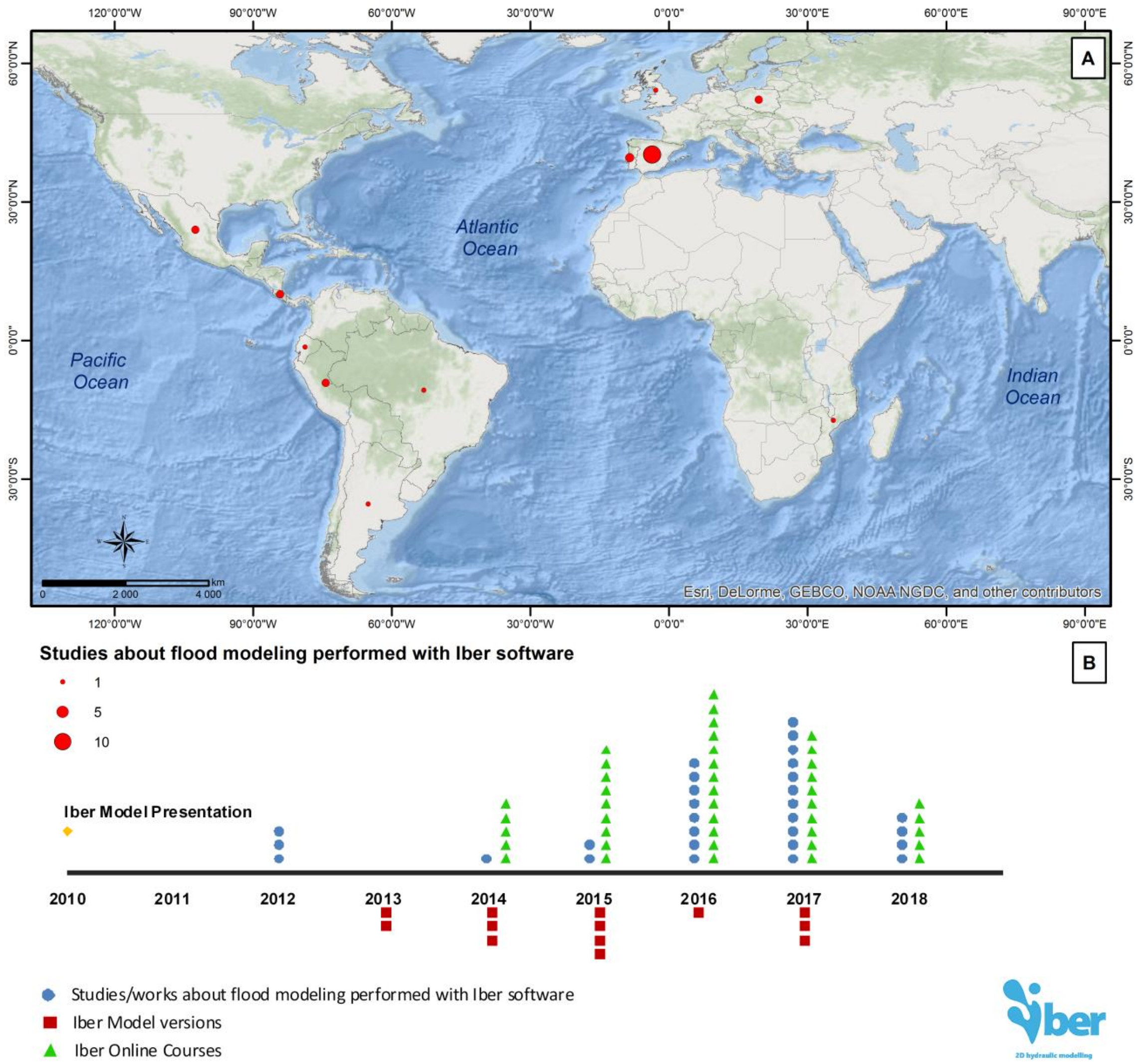

Figure 1: A) Map of the geographical distribution by country, of the areas analyzed in the studies of flood modeling with Iber; B) Timeline of flood modeling studies performed with Iber and also the released versions and online courses of the Iber Model [Scopus, 2018; Web of Science, 2018; Iberaula, 2018]

3. Methodology

As previously mentioned, it was chose Iber software to perform hydraulic modeling, since it is a very useful tool to solve problems involving different fields, such as the assessment and management of flood risk. In addition, Iber consider a two-dimensional mathematical model that offers advantages compared to the one-dimensional models, giving greater stability and precision in the results, since it is able to simulate the water flow with more adjustment to reality in all the situations in which the flow of the water is not exclusively unidirectional [Soto and Malpartida, 2016]. The two-dimensional models do not consider the river as a line with a sequence of cross sections that allow the definition of the channel geometry (one-dimensional models), but as a mesh composed by polygonal elements [Caraguay and Alcívar, 2018]. On the other hand, two-dimensional modeling requires longer computation time, entail a greater computational capacity and the results are very dependent on the quality of the source data introduced in the software [Caraguay and Alcívar, 2018].

Iber presents three different calculation modules: the hydrodynamic module, the turbulence module and the sediment transport module [Blabé *et al.*, 2012]. The hydrodynamic module, which is the basis of all the processes included in this tool, solves the

2D Shallow Water Equations, also known as two-dimensional equations of *Saint Venant* (Figure 2). These equations are divided into three parts: the first represents the continuity equation and the other two represent the equations for the conservation of momentum in the two orthogonal directions [Bladé *et al*., 2012; Mignot *et al*., 2006].

$$\frac{\partial h}{\partial t} + \frac{\partial hU_x}{\partial x} + \frac{\partial hU_y}{\partial y} = 0$$

$$\frac{\partial}{\partial t}(hU_x) + \frac{\partial}{\partial x}\left(hU_x^2 + g\frac{h^2}{2}\right) + \frac{\partial}{\partial y}(hU_xU_y) = -gh\frac{\partial Z_b}{\partial x} + \frac{\tau_{s,x}}{\rho} - \frac{\tau_{b,x}}{\rho} + \frac{\partial}{\partial x}\left(v_t h\frac{\partial U_x}{\partial x}\right) + \frac{\partial}{\partial y}\left(v_t h\frac{\partial U_y}{\partial y}\right)$$

$$\frac{\partial}{\partial t}(hU_y) + \frac{\partial}{\partial x}(hU_xU_y) + \frac{\partial}{\partial y}\left(hU_y^2 + g\frac{h^2}{2}\right) = -gh\frac{\partial Z_b}{\partial y} + \frac{\tau_{s,y}}{\rho} - \frac{\tau_{b,y}}{\rho} + \frac{\partial}{\partial x}\left(v_t h\frac{\partial U_y}{\partial x}\right) + \frac{\partial}{\partial y}\left(v_t h\frac{\partial U_y}{\partial y}\right)$$

Figure 2: 2D Shallow Water Equations [Blabé *et al*., 2012]

All software modules work on an unstructured mesh of finite volumes formed by triangular or quadrilateral elements. In other words, the software code solves the shallow water equations through a numerical scheme in finite volumes for unstructured two-dimensional mesh [Cea *et al*., 2009]. In this finite volume method, the variables involved in the calculation, such as water depth and velocity, are stored in the geometric center of each polygon, also referred to as node point on a mesh, representing the mean value of each element [Bladé *et al*., 2012].

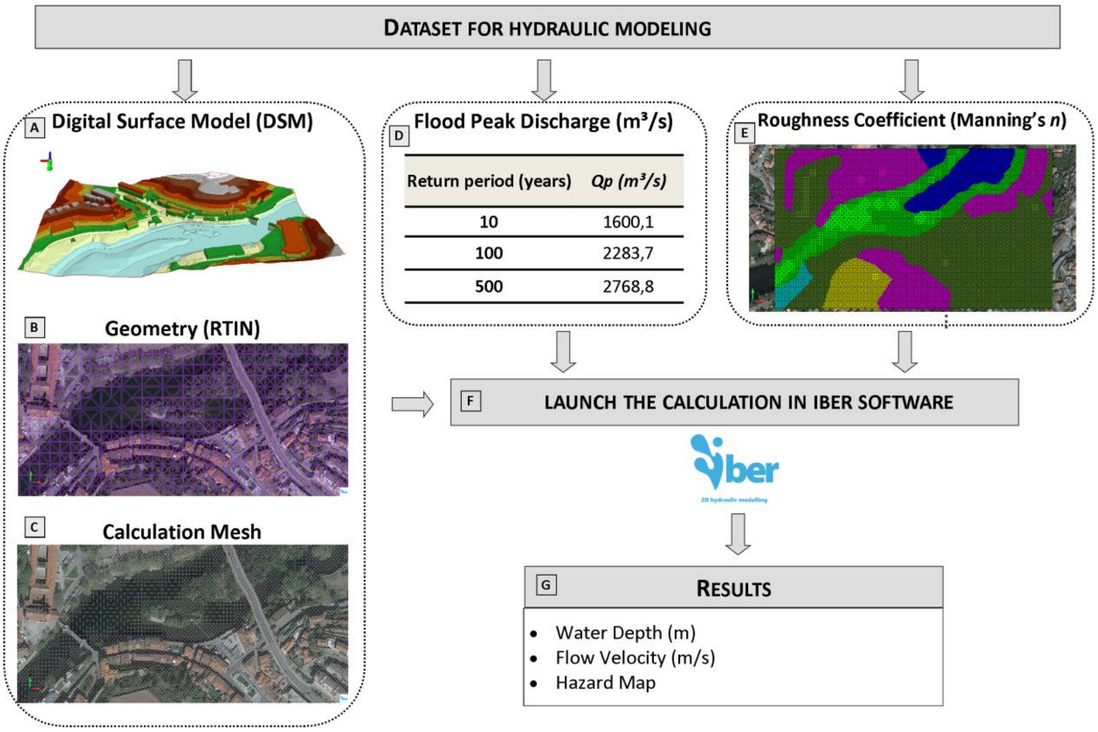

Figure 3: Methodological scheme followed in this work.

The Iber software is structured in three main steps: pre-process, process and post-process. In the first step (pre-process), we define or import the geometry, determine the conditions of the problem, assign the roughness values, create the calculation mesh, etc. In the second step (process) the calculation is launched and, in the third (post-process), we visualize the obtained results. In order to complete the various steps, we need basic data that are later introduced in the software, such as a detailed digital surface model (DSM), the values of peak flood discharges and the assignment of the Manning coefficient values for

each type of land use (Figure 3). One of the most important elements in hydraulic modeling of flooded areas is the Digital Surface Model, which has to be very detailed because the floods are strongly conditioned by the terrain features. After the preparation of the digital surface model, we started the simulation in Iber with the import of the geometry. Since this is a two-dimensional model it allows importing geometries automatically from the digital surface model. Although there is a great diversity of formats that allows to import geometries, in this study we choose the RTIN methodology (Right-Triangulated Irregular Network) that divides the surface of the terrain into triangles rectangles of various sizes. Figure 3B shows the geometry that was defined through the digital surface model import (Figure 3A), generating then the calculation mesh (Figure 3C) that has the triple of the elements existing in the geometry to represent properly the flooded areas. Then, it was defined the boundary conditions where we assign the values of the flood peak discharge for a certain return period (Figure 3D), also defining for the whole model the initial condition of the water depth. The roughness of the surface was assigned automatically through the Manning roughness coefficient (Figure 3E). For this, it is necessary to have an ASCII (*.asc*) file with the respective land uses, and another file (*.csv*) with a list of them.

Finally, we determine the simulation data where the time parameters are defined, such as the maximum simulation time and the interval results. After performing all these procedures, the calculation is launched and, when it finishes, it is possible to visualize the results.

4. Study Area

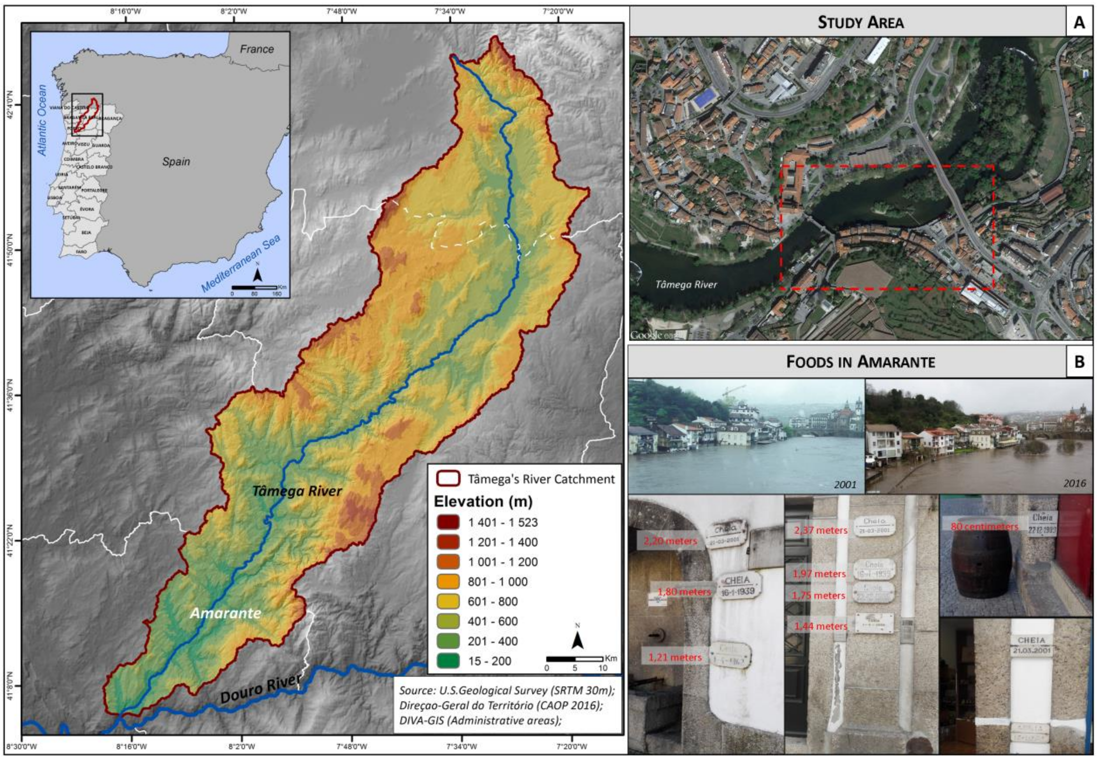

Figure 4: A) Location of study area; B) Floods in Amarante.

The city of Amarante, located in the northern region of Portugal, belongs to the Tâmega River catchment. This watershed has an area of approximately 3314,77 km², and Tâmega River, an international stream, has a length of about 187,59 km (Figure 4A).

The historical and urban center of the city of Amarante is frequently affected by floods (Figure 4B) and there have been records of these extreme events since the 17th century, more

specifically since 1699 where a large flood occurred, according to historical records [Tedim *et al*., 2010]. The chosen area for the hydraulic modeling corresponds to a small sector of the Tâmega River (~580m) in its passage through the Amarante urban center (Figure 4A), where exists a big number of exposed elements to the floods, such as coffee shops, restaurants and stores, which in case of flood suffer high damages and losses (Figure 4B).

5. Results and Discussion

The flood modeling tools, such as the Iber software, allow the calculation of distinct hydraulic parameters, resulting in the different maps displaying flood characteristics - flood extent map, flood depth map and flood danger map - which help to assess and manage flooded areas. As MOEL et al. [2009] says, maps representing the maximum extent of a flood for a specific event are the most common flood hazard maps, which may describe a historical episode or a particular event with a certain return period.

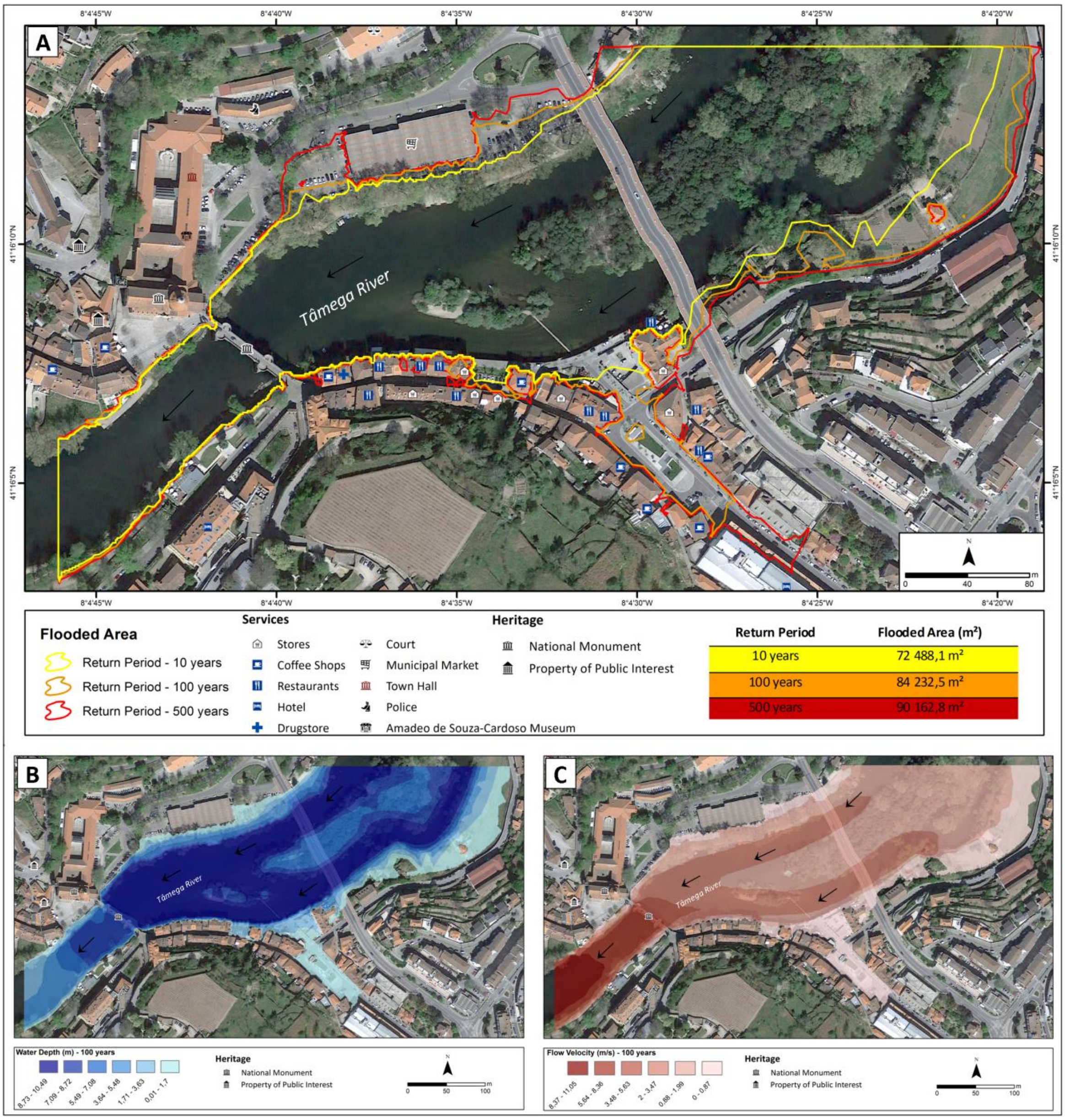

Figure 5: A) Flood extent map (10, 100 and 500 years); B) Flood depth map (100 years); C) Flood velocity map (100 years).

In this case, it is important to highlight the differences between the flooded area with distinct return periods, being the maximum extent of ca. 72 488.1 m² which was reached by an event with a 10-year return period, for a 100-year return period it is 84 232.5 m², and for 500-year is approximately 90 162.8 m² (Figure 5A).

As mentioned before, another result was obtained with hydraulic modeling performed with Iber such as water depth and flow velocity, respectively presented in figure 5B and 5C, for an event with a 100-year return period. Analyzing these results, it is possible to see the influence that the existing bridge in the study area (São Gonçalo Bridge) has in the water depth, causing an upstream growth, since it acts as an obstacle to the free movement of the flow, as well in the flow velocity that increases progressively downstream of the bridge. Thus, in a potential flood event with a return period of 100 years, the water depth outside river banks can reach almost 4 meters, especially on the left bank which is particularly affected.

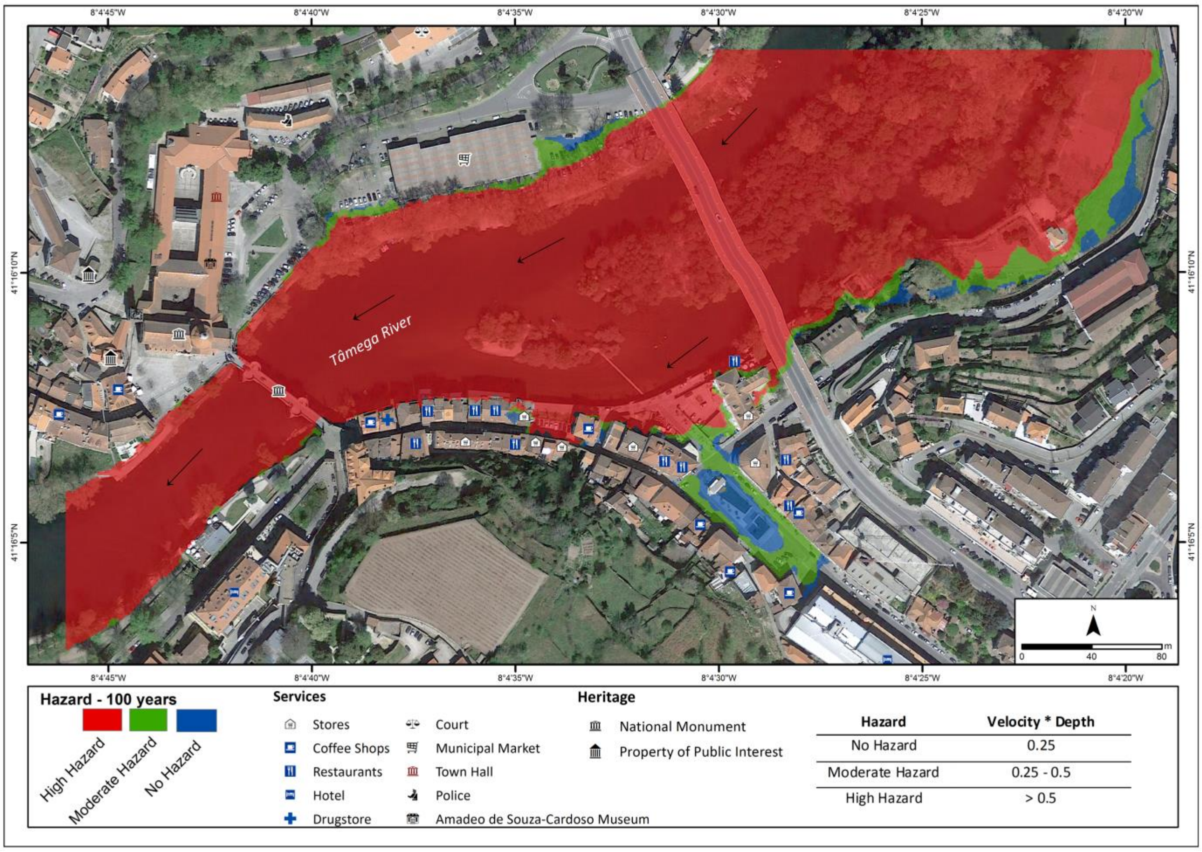

Figure 6: Flood danger map.

The Iber software calculates the flood danger according to the Spanish legislation stipulated in Royal Decree of 9/2008. These types of maps are the result of the combination of water depth and velocity variables. Figure 6 shows the flood danger under Spanish legislation, for a 100-year return period, highlighting the worrying situation on the left bank of the Tâmega river, which due to the high concentration of activities and services, in case of flood, it causes many constraints to the normal work of these establishments, as well as losses and damages.

6. Conclusion

In the present paper it was presented the results obtained from the application of a model that solves the 2D shallow water equations to obtain water depth and flow velocity, essential parameters to do an assessment and management of flooded areas. Thus, through the use of the Iber software it was possible to define the flooded areas for potential flood events with 10, 100 and 500-year return periods, as well as the determination of the values assumed by the hydraulic variables, water depth and velocity.

Although the Iber model provides good results, their quality is quite dependent on the input dataset we introduce to the software, such as the digital surface model (DSM) that needs to have a lot of detail to accurately represent the characteristics of the terrain.

Despite flooding events in the Amarante city are very frequent, at national level, it is not considered as a critical area for floods. Therefore, the present work represents a contribution to the study of the floods in this city since there are no studies of this type for this area. The mapping of flooded areas is essential for an adequate spatial planning, helping in the decision making and the suggestion of measures related to the emergency planning. Furthermore, these results allow knowing the most danger areas to the occurrence of floods, being important instruments of territorial management.

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