The “Flood Damage Model” Repository

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Abstract. Flood damage assessment is a quite recent topic in flood risk management, nevertheless, several tools are now available for flood damage estimation which are characterised by different levels of robustness and reliability, and no model can be, at present, considered as a standard. In such a context, the choice of the more suitable model(s) to be implemented can be challenging, above all for non-expert users, and may imply significant errors in damage estimates if done without a critical knowledge of models’ limits and usability. Key questions concern the coherence between the scales of analysis, the type of flood or the vulnerability context, the ability to cover the variety of exposed assets and last but not least the specific inputs required and available data. The “flood damage models” repository is aimed at supporting flood damage modellers in the choice of the best available model(s) for a specific context under investigation and a specific problem at stake, by supplying key information for each available model. With this objective in mind, the repository wants to be more than a review or a database of existing models, but rather an operative tool in the support of more reliable analysis.

1 Introduction

Floods are the most frequent and costly natural hazards, affecting the majority of countries at global scale and on regular basis (UNISDR, 2011; ICPP, 2012). According to the EM-DAT database, during the period 1900-2019 Europe experienced 628 major floods that caused more than 9 thousand fatalities, affected about 17 million people and cost about 145 billion of billion \$ (EM-DAT, 2020). Moreover, there is a growing concern that flood risk will have an increasing trend in the future, due to climate-change and socio-economic development, enhancing the awareness for flood risk mitigation (Barredo, 2009; Alfieri et al., 2018).

Risk is commonly defined as a function of hazard, exposure and vulnerability (ICPP, 2012). More specifically, flood risk is defined as the expected damage that may occur in a certain period of time due to inundation phenomena. Hence, risk can be determined by the combination of hazard and damage quantification. In the past, flood risk assessments and policies were often not well balanced, ignoring the assessment of damage and focusing on the reduction of the probability of occurrence and intensity of inundations (Merz, 2010).

Still, with the recent shift from hazard control to flood risk management, flood damage assessment became a key prerequisite in any deliberation of cost-effectiveness of flood mitigation measures, analyses of vulnerability and resilience, land use planning, flood risk mapping, comparative risk analyses and financial appraisal (Merz, 2010).

The operative tools used for flood damage assessment are the flood damage models which describe the relationship between hazard, exposure and vulnerability parameters and the damage itself.

Despite the flood damage assessment is a quite recent topic in flood risk management, there is a wide variety of models available, in the literature, for the estimation of flood damage. All of them are characterized by different levels of complexity, robustness and reliability, but no model can be, at the moment, considered as a standard.

Every model is strictly valid for specific contexts and objectives; as a result, selecting the most appropriate model for a specific problem at stake can be critical, especially for non-expert users, who may lack of knowledge about the model’s limits and usability.

In fact, flood damage models are developed to be applied at a specific scale, for a specific type of flood, focusing on a specific exposed item and vulnerability context, and require specific input data. However, the development and evaluation of flood damage models doesn’t always go together with detailed information about when and where a certain model should be applied, or even the model does not always have an explicit calibration and validation, that document and demonstrate how the model performs and how accurately it is (Molinari, 2020).

In such a context, the implementation of a model in a framework different from the calibration one (i.e. different scale of application, different type of floods and even different exposed items) may imply significant errors in the damage estimation.

To fill this gap, this study presents an operative tool to collect and organise information about available flood

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damage models: the Flood Damage Model Repository (FDM). The FDM is aimed at supporting flood damage modellers, especially non-expert ones, in the choice of the best available model(s) for a specific context under investigation and a specific problem at stake, by supplying (for each available model) key information that, if ignored, can lead to improper use of models and then significant errors in flood damage assessment. In this way, it represents an opportunity to bridge existing knowledge gaps on flood damage assessment tools, although the attention is presently focused only on direct damage.

2 Conceptual model

In order to describe each flood damage model, a conceptual model was developed (Fig. 1). This has been conceived in order to include all the specifications of the models, leading to their proper application.

Figure 1. Conceptual model

In detail, according to the conceptual model, each flood damage model is characterized by: the context of investigation, its identification attributes (ID), the input and output parameters, information on calibration and validation, information on transferability, and the bibliographic references. For each of this aspect/field, univocal attributes are the identified.

More specifically, the context of investigation is defined by the country of development, the scale of the analysis, the flood type, the model type and the exposed items or sectors (Fig. 1). The country of development represents the geographical region in which the model has been derived and calibrated. The scale of analysis indicates whether the model refers to single item at risk like a building or a farm (i.e. micro scale model), to spatial aggregations of exposed items, such as land use areas or administrative units, typically with size ranging from 1 km² to 1 ha (i.e. meso scale model), or to larger spatial units, such as municipalities or even countries (i.e. macro scale models) (Merz, 2010). Flood type consists of two different attributes, aiming at identifying the main features of the hazard for which the model works. The first distinguishes among riverine floods caused by the overtopping of riverbanks, pluvial floods caused by rainfall or snowmelt, and coastal floods caused by the

incurion of the marine water. According to the second attribute, floods are instead categorized as low-velocity or high-velocity events. Low velocity floods are typical of big river basins, with high static loads. On the contrary, high-velocity floods mostly correspond to flash floods, typical of dam breaking or small river basins with high sediment transport and high dynamic loads. The model type consists of three different attributes. “Model type I” refers to the expression of the loss, i.e. relative or absolute models, whereas relative models express the expected loss as a ratio of the total asset value at risk while absolute models estimate the loss directly in monetary or quantitative units. “Model type II” indicates if a model is empirical, synthetic or mixed. Empirical models are calibrated with observed flood damage data collected after real flood events. Synthetic models are based on the investigation of damage mechanisms and hypothetical damage estimates by experts through what-if-analysis; this approach is often used when empirical data are not available or of uncertain quality (Gerl, 2016). Mixed refers to the combination of the empirical and the synthetic approach. “Model type III” finally describes the modelling approach adopted by the model, between deterministic or probabilistic. At the end of the “context of investigation” field, the exposed items or sectors for which the flood damage model is developed are referred.

The identification field represents the distinctiveness unit of each model. A model is characterized by its name, its authors and its year of publication (Fig. 1). Each model can have then linked models, which represent the upgrading version of the model itself or even the application of the same model to different exposed items or sectors or at different spatial scales. The fundamental attribute that distinguishes the model is its expression. The relationship between the explicative variables (hazard, exposure and vulnerability related) and the flood damage is usually illustrated by graphs, formulas or software.

The model inputs field provides information about the parameters implemented in the model. Here, a further distinction is essential (Fig. 1). “Hazard parameters” describe the intensity of the flood event, like the flood depth, the flood velocity and the flood duration. “Exposure parameters” physical quantify what can be damaged because of an inundation event. They are, for example, the number of buildings, the area of the agricultural parcels or the length of the roads. However, an exposure parameter can be very often an economic quantification of the exposed asset(s), such as the maximum damage. “Vulnerability parameters” finally describe the susceptibility of the exposed items to be damaged during a flood event. For example, for what concerns buildings, vulnerability parameters can refer to the construction materials, the year of construction, the presence or not of a basement. Concerning instead crops, vulnerability parameters can be represented by the species, the vegetative stage of the plants, etc.

The model outputs field explains what the model output is. For example, regarding buildings, models can estimate the damage to the structure or the damage to the structure plus contents, inventory, etc. Also, the elements that contribute to the evaluation of the damage are clarified. Consequently, it is specified, for example, if the

model output refers to the entire volume of the building or only to the flooded floors.

Among the most important information on calibration there are the context in which the model at issue was calibrated, the dimension of the dataset used in the process and the quality such data (Fig. 1). The calibration context describes both the hazard and the exposure/vulnerability features of the area in which the model was derived. The type of flood, the values of flood depths or velocities, the presence or not of solid transport or pollutants, are some typical characteristics of flood events. Information about exposure/vulnerability could include, instead, morphological information, structural typology of buildings, types of crops, etc. This section helps the user to understand in which context the model is more reliable. The dimension of the dataset represents the amount of data used to calibrate the model. “The quality of the data” attribute describes the data used for the model calibration. It makes clear, for example, if the flood and damage data are observed or modeled. In this way, the reliability of the calibration process is appreciated.

Information included in the validation field is similar to the calibration one (Fig. 1). The validation context describes the hazard and the vulnerability features of the context in which the model at issue has been verified. It also highlights if the validation is carried out with a specific technique. “The dimension of the dataset” represents the amount of data used to validate the model and “the quality of the data” describes the data used for validation. Information is also included about the estimation error derived from the validation process. Finally, in the cross-validation attribute, it is possible to list studies where the treated model is compared with other existing models in the literature.

The transferability field provides information on the transferability and applicability of the model (Fig. 1). In detail, the former attribute contains information on how easy is for a scientist to transfer the model in another context considering the expression of the model, available information on derivation or calibration, etc. The second attribute gives information on what are the main issues that can arise in the application of the model, especially from a point of view of a non-expert user.

In the bibliography field, there are the scientific papers or books in which the model development is described.

3 Implementation

3.1 Construction of the database

The definition of the conceptual framework has been followed up by its transformation into a database. A database indicates a set of structured or homogeneous information, stored in an electronic computer, and searchable by specific keywords. The database construction process requires the support of a software library. In this study, a high quality, visual and open source tool to create, design and edit database files compatible with SQLite has been used. The database structure has been designed following the entity-relationship model. In this application, the flood damage model is the only entity,

characterized by its own attributes, i.e. those included in the conceptual model. The models have no relationship with each other. Every model is identified with a unique primary key, i.e. the identification attributes.

The attributes included in the “context of investigation” field correspond to the database’s filters. The user can make use of these filters in order to browse the more suitable flood damage model(s) according to their needs. Nevertheless, the database will most likely return multiple models, especially when few filters are selected.

3.2 Implementation of the website

The digital construction of the Flood Damage Model Repository database is associated with its implementation in a website, which is the effective operative tool that the user handles. The website consists of three pages: the landing page, the main page and the model specification page.

The web page that visitors reach after clicking the Flood Damage Model Repository specific URL (fdm.polimi.it) is the landing page, which highlights the key features of the FDM, its capabilities and its operating mode. It is composed by three sections.

The first section includes sliding flood inundation images with keyword phrases that explain the FDM purpose (Fig. 2).

Figure 2. Flood inundation image with keyword phrases

The second section is composed by an animated bubble chart, which summarises the countries for which the flood damage models presently included in the repository have been developed, and the available flood damage models for the specific country (Fig. 3).

The third section is the “Get Involved” section, which is divided into two boxes (Fig. 4). The first box allows the user to contact the FDM developers, for any doubt or clarification. Here, the users can also contribute to the development of the repository by submitting their own model. The second box includes an operative counter, capable of counting in real time the number of the models uploaded in the repository as well as the number of the models that are under investigation by the developers but have not been uploaded yet. The “not uploaded” button opens a webpage, more specifically the work in progress section (see below), in which all these models are listed and linked to their respective bibliography.

Figure 3. Bubble chart

Figure 4. Get Involved section

Figure 5. Header menu

As regards to the main page, it can be easily reached just clicking on the “Navigate the FDM Repository” button on the landing page. It consists of four parts, the header, the central body, the sidebar and the footer.

The header contains the distinctive elements of the website, such as the logo and the navigation menu (Fig. 5). The navigation menu includes three elements, the “about” section, the “get involved” section and the “discover more” section. In the “about” section the main objectives of the Flood Damage Model Repository are explained in detail, also by means of a video. In the “get involved” section the users can download the requirements paper explaining how to contribute to the repository with their own model. The “discover more” section allows the user to select between two options. The first option leads the users to the “cross-validation” section, in which they can find studies where different flood damage models are compared among each other and/or applied in different contexts with respect to the calibration one, with a link to their respective bibliographic reference (see Sect. 2). The second option opens a page in which there is a list of flood damage models not contained in the database yet but under investigation, i.e. the so-called “work in progress” section.

Second, in the central body of the main page there is the list of the uploaded flood damage models (Fig. 6). The user can search a specific model using the search bar placed on the top of the list by entering its name. Each model links to the model specification page, describing all the attributes of the model according to the conceptual model described in Section 2. Moreover it includes graphs in which the model is compared with similar models included in the database that are characterized by the same attributes as for the scale of analysis, the sector and the

model type. Such graphs help the user to understand how the model evaluates the damage in comparison with several other models that can be considered similar to it. The more similar models are available, the more effective comparison turns out to be.

Next to the list there is a sidebar including the filters for browsing the flood damage models (Fig. 7). The user selects the features of the model they need and then the website filters the model(s) which best fits the requirements. The sidebar is accompanied by a legend that describes the meaning of each filter (see Sect. 2).

Search model
AGRIDE-c for the Po region
Bignami et al. (bivariate model)
Bignami et al. (urban coverage index)
Bignami et al. (water depth)
Bignami et al. (water velocity)
Dutta et al. for agricultural crops
Dutta et al. for non-residential buildings
Dutta et al. for residential buildings

Figure 6. List of uploaded models

Figure 7. Filters for browsing

Figure 8. Footer menu

Finally, in the footer, the most important information is summarized (Fig. 8). The organization who offers the FDM service is referred and the frequently asked questions are explained. Moreover, the terms of service and copyright as well as the privacy policy are mentioned informing the user about the processing of the personal data.

The Flood Damage Model Repository will be permanently online and available for all the users. It will be the result of the work of many modellers and researches. For this reason, the need to obtain a licence was essential. In FDM, the CC BY licence has been chosen, which allows the user to share and modify website contents (Creative Commons, 2020).

Exposed item/sector	Models
Residential buildings	Dutta et al. for residential buildings FLEMOps+ at the microscale FLEMOps+ at the mesoscale FLFArs FLF-IT INSYDE JRC for residential buildings (Africa) JRC for residential buildings (Asia) JRC for residential buildings (Europe) JRC for residential buildings (North America) JRC for residential buildings (Oceania) JRC for residential buildings (South/Central America) Luino et al. Merz et al. Multi – Coloured Manual Oliveri and Santoro SEMP SMV SREG _a SREG _d SREG _d USACE depth-damage functions for residential buildings
Non-residential buildings	Dutta et al. for non-residential buildings
Agricultural crops	AGRIDE-c for the Po region Dutta et al. for agricultural crops JRC for agricultural crops (Africa) JRC for agricultural crops (Asia) JRC for agricultural crops (Europe) JRC for agricultural crops (North America)
Commercial sector	FLFAcs JRC for commercial sector (Asia) JRC for commercial sector (Europe) JRC for commercial sector (North America) JRC for commercial sector (Oceania) JRC for commercial sector (South/Central America)
Industrial sector	JRC for industrial sector (Africa) JRC for industrial sector (Asia) JRC for industrial sector (Europe) JRC for industrial sector (North America) JRC for industrial sector (South/Central America)
Infrastructure (roads)	JRC for infrastructure (Asia) JRC for infrastructure (Europe)
Transports	JRC for transport (Asia) JRC for transport (South/Central America)
Vehicles	USACE depth-damage functions for vehicles
Multi – sectoral models	FLEMOcs+ Bignami et al. (water depth) Bignami et al. (urban coverage index) Bignami et al. (water velocity) Bignami et al. (bivariate model)

3.3 Database filling

About fifty flood damage models have been already implemented in the database, which cover different exposed items or sectors (Table 1). The exposed items or sectors investigated so far are:

- Residential buildings
- Non-residential buildings
- Agricultural crops
- Commercial sector
- Industrial sector
- Infrastructure (roads)
- Transports
- Vehicles

The ampler category is represented by models developed for the residential sector at the micro scale. However, the goal of the Flood Damage Model Repository is to contain as many flood damage models as possible in order to become even more reliable, robust and complete. Consequently, continuing efforts to increase the number of models are underway.

4 Conclusions

This paper presents the Flood Damage Model Repository, an operative tool supporting flood damage modellers in the choice of the best available model(s) for the estimation of flood damage, in a specific context, and for a specific problem at stake. To this aim, fundamental information is provided for each model, in order to allow its proper implementation, and to highlight its potential limitations and strengths.

Accordingly, the repository is more than a database but it is a tool to increase knowledge gaps on flood damage assessment tools, for more reliable flood damage evaluation. In fact, a critical issue leading to the improper use of models, and then significant errors in flood damage estimation, is the lack of detailed information about how the model was developed, when and where a certain model should be applied, or even whether a model has an explicit calibration and validation that documents and demonstrates how it performs and how accurate it is (Molinari, 2020).

The ultimate goal of the Flood Damage Model Repository is to contain as many flood damage models as possible in order to become even more complete, robust and reliable. To achieve this goal, the involvement of flood damage modelers and researchers from all over the world will play a major role; their knowledge and experience can contribute not only to the enlargement of the existing database but also to the verification of the flood damage models that are already included.

All researchers working in the field of flood risk are encouraged to contribute in and share their experience to reach the common goal of improving flood damage and risk estimates.

Table 1. Available models categorized by exposed item/sector.

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