Int J Appl Earth Obs Geoinformation 73 (2018) 220–229

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Using *FloodRisk* GIS freeware for uncertainty analysis of direct economic flood damages in Italy

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ARTICLE INFO

Keywords:
Flood risk
Economic damages
Uncertainty analysis
GIS
Depth-dammage curves
Italy

ABSTRACT

The considerable increase in flood damages in Europe in recent decades has shifted attention from flood protection to flood risk management. Assessments of expected damage provide critical information for flood risk management efforts. The evaluation of potential damages under different flood scenarios through quantification of their ability to provide relative short-, medium- and long-term risk reduction, supports decision-makers in discriminating among several alternative mitigation actions. End-users should be aware of, and knowledgeable about, the limitations and uncertainties of such analyses, as well-informed decisions regarding efficient and sustainable flood risk management will become increasingly relevant under future climate and socio-economic changes. In this context, a method was developed to identify and quantify the role of the input parameters in the uncertainty of the potential flood economic damage assessment in urban areas with low sloping/flat terrain and complex topography using a GIS-based, free and open-source software called *Floodrisk*. Sets of plausible input parameters for the model's two flood loss modelling subroutines (hydraulic modelling and damage estimation) were dynamically combined to quantify the contribution of their inner parameters to the total damage assessment uncertainty. To estimate the contributions of each input to overall model uncertainty, the combination of input parameters that minimized the error in the spatial distribution assessment of the extensive damages affecting (downtown) Albenga (Italy), enumerated after the historical Centa River flood of November 5, 1994, was taken as a reference. In this specific case, a high epistemic uncertainty for the damage estimation module was noted for the specific type and form of the damage functions used. In the absence of region-specific depth-damage functions, the vulnerability curves were adapted from a range of geographic and socio-economic studies. Given the strong dependence of model uncertainty and sensitivity to local characteristics, the epistemic uncertainty associated with the risk estimate was reduced by introducing additional information into the risk analysis. Implementing newly developed site-specific curves and a more detailed classification of the construction typology of the buildings at risk, led to a substantial decrease in modelling uncertainty, along with a decrease in the sensitivity of the flood loss estimation to the uncertainty in the depth-damage function input parameter. These findings indicated the need to produce and openly disseminate data in order to develop micro-scale risk analysis through site-specific vulnerability curves. Moreover, this study highlighted the urgent need for research on the development and implementation of methods and models for the assimilation of uncertainties in decision-making processes.

1. Introduction

Within Europe, economic damage arising from flooding events represents roughly one third of the costs incurred due to natural disasters (Garrote et al., 2017). The sharp increase in European countries' overall flood damage costs, from 9 G€ in the 1980s to over 13 G€ in 2000 (Papathoma-Kohle et al., 2015), was concomitant with an increase in flood event intensity and frequency (Mallakpour and Villarini, 2015). Nineteen of the world's twenty most populated agglomerations are located along or at the outlet of watercourses (Demographia World Urban

Abbreviations: CBA, cost-benefit analysis; CV, coefficient of variation; DTM, digital terrain model; EAD, estimated annual damages; EPL, exceedance probabilityloss; FLORA2D, FLOod and roughness analysis in two dimensions; FOSS, free and open source software; GIS, geographic information system; IDW, inverse distance weight; IQR/M, interquartile range divided by median expressed as percent; ISTAT, Italian National Statistical Institute; MAE, mean absolute error; MU, maximum uncertainty range; NLCDUS, National Land Cover dataset; Q-H, flow rate—head (curve); RMSE, root mean square error; RU, reduced uncertainty range

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https://doi.org/10.1016/j.jag.2018.06.019
Received 26 February 2018; Received in revised form 25 June 2018; Accepted 25 June 2018

Areas, 2016). Advantageous from many economic and social points of view, these locations will likely see a rise in population and socio-economic activities, thereby increasing their vulnerability to floods (Domenighetti et al., 2015). In turn, this will - all climate change influences aside - magnify the possibility of flooding events which can turn into disaster events (Mitchell, 2003). Given present and predicted future trends in the frequency, intensity and consequences of flooding events, the limitations of flood protection approaches predicated on absolute safety have become apparent (Pahl-Wostl, 2007). Accordingly, European nations are slowly shifting towards an approach focused on considering interactions between hydrological and socioeconomic factors and managing flood risks (De Moel et al., 2009). As the assessment of expected flood damage is a key element in designing an effective risk mitigation strategy, flood risk models have a critical role in supporting decision-makers in the prioritization of mitigation actions and the efficient use of limited financial resources when facing a wide range of intervention alternatives (Albano et al., 2017a).

Risk information must be scientifically and technically rigorous, open for review and honest about its limitations and uncertainties; failure to conform to these criteria can lead to flawed and misleading decision-making. The adoption of collaborative and open source geospatial models for the reliable estimation of present and future flood-engendered losses, while crucial to maintaining and improving the credibility, efficiency and transparency of risk management decision-making processes, is not particularly useful if the specialists producing the risk information do not clearly and simply communicate the uncertainties associated with the process. A risk model can produce a very precise result but, in reality, the accuracy of the model and input data may provide only an order of magnitude estimate. For example, if uncertainty is ignored, sharply-delineated flood zones on a hazard map will not adequately reflect the uncertainty associated with the estimate, potentially leading to decisions such as locating critical facilities just outside the "flood line," where the actual risk is the same as if the facility had been located inside the flood zone (World Bank, 2014).

The many available flood loss estimation models and/or software packages (e.g. FloodRisk by Albano et al., 2017b; CAPRA-Flood model by the World Bank; HIS-SSM by Kok et al. (2004); HAZUS-MH Flood Module by FEMA; HEC-FIA by the U.S. Army Corps of Engineers; InaSAFE-Flood by AIFDR, RiskScape-Flood by GNS and NIWA; Kalypso by Hamburg University of Technology and Bjoernsen Consulting Engineers) means there are multiple ways to simulate each model component.

Users may choose from software packages that are proprietary, open access or open source, and that have varying degrees of complexity and usability. Open source provides a more transparent framework than open access and proprietary software packages (e.g. FloodRisk; HIS-SSM, HAZUS-MH Flood Module, HEC-FIA, RiskScape-Flood), and allows the science and assumptions behind the models to be checked and sensitivity or uncertainty analysis undertaken (World Bank, 2014).

Moreover, despite the fact that some of the aforementioned flood loss methods incorporate similar calculation philosophies, the more flexible open source software allows advanced users to provide additional building and classification types, temporal variability in population and demographics, new risk indicators and supplemental socio-economic parameters once relevant checks have been made to the applicability and scope of analysis. For example, the most appropriate model may vary by region (e.g. socio-economic aspects, hydrology, morphological characteristics, monitored or ungauged basin, etc.), scale (i.e. global/continental, macro-, meso- and micro-scale), type of flood hazard (e.g. flash, river, pluvial, infrastructure failures) and scope of analysis (e.g. planning, insurance, post-event scenarios, forecasting, early warning, etc.), because data availability and specificity vary. Indeed, several flood models are calibrated or set for a specific country condition such as Kalypso or Hazus-MH; others use too few damage categories, which often provides a level of analysis with insufficient detail (e.g. InaSAFE-Flood determines asset losses in terms of a binary, i.e. 1 or 0, vulnerability function).

There are substantial differences (geographical, hydrological and social) in the underlying approaches of GIS flood risk models, which require specific approaches for different applications and in different countries. The proposed study does not aim to help potential users identify the optimal model(s) on the basis of their functionality, quality and usability of the software package. Instead, this research quantifies the uncertainty of flood damage assessment at a micro-scale in order to identify the most sensitive sources of uncertainties, while also showing the importance of reducing these uncertainties.

Identification of the relative roles of model parameters allows us to pinpoint weaknesses in the damage analyses (e.g. Which hypotheses guide the result?), and to orient efforts to assemble additional information and improve risk analyses (e.g. Which data are most important to reducing uncertainty?).

The quantification and communication of uncertainty is important to making informed decisions (Ascough et al., 2008), and can increase stakeholder engagement and active participation, which enhances the legitimacy of decision-making processes as well as their acceptance (Inam et al., 2017a,b). Given the importance of communicating uncertainty to decision-makers who may have different perspectives or prejudices against risk or regarding prevention and mitigation measures, it is important that uncertainty quantification be integrated into flood damage analysis and assessment and communicated to end users (Downton et al., 2005). Specifically, flood damage uncertainty analysis should consider and quantify the most sensitive sources of uncertainty so that additional resources can be applied to effectively improve models, data and their understanding. The greater portion of the scientific literature has focused on addressing individual components of uncertainty: Scorzini and Leopardi (2017) focused on the uncertainty in damage functions; Glas et al. (2016) analyzed the sensitivity related to the availability and accuracy of land use data; while others have addressed the challenge of quantifying the uncertainty within hydrological-hydraulic modules (Altarejos-Garcìa et al., 2012; Penna et al., 2014; Papaioannou et al., 2016). Questioning how uncertainty may impact the robustness of flood management decision-making, a limited number of studies have addressed how combinations of uncertainty sources interact and propagate through flood damage assessments (Freni et al., 2009; Merz and Thieken, 2009; Saint-Geours et al., 2013; De Moel et al., 2014; Chinh et al., 2016). The cited studies differ principally by the components under investigation (e.g. extreme value statistics, hydraulic model, potential dyke breach, inundation mapping, exposure assessment, damage functions, project costs), and vary in the scale of applications, complexity of the models utilized, as well as the availability and detail of data. A non-exhaustive comparison of recent studies that aim to rank sources of uncertainty is provided in Table 1.

The present study's main contribution was to identify and quantify, under data scarce conditions, the role of input parameters in the uncertainty of a micro-scale flood risk model's outputs for a built-up area with complex topography using the free and open source GIS software *FloodRisk* (Albano et al., 2017b). This study is also original in that it considers damage-modulating parameters neglected in past studies (Table 1). Estimating damages in urban areas located on flat terrain with complex topography (e.g. roughness factors, digital terrain model resolution) requires a more detailed scale of analysis (e.g. economic asset inventory at the building scale, a hydraulic model based on a fully dynamic approach and not on simplifications, which are attractive but inappropriate), only achievable with more complex models featuring spatially-distributed uncertainty. Situated at the mouth of the Centa River, the town of Albenga, Liguria (Italy), has suffered several flood events, including one such event on November 5, 1994. This served as a case study for a pilot investigation of damage prediction uncertainty and the factors which influence it.

Knowledge of the magnitude and source of uncertainties helps to improve assessments and leads to better informed decisions on flood risk mitigation alternatives (Saint-Geours et al., 2013; De Moel et al.,