ICARIA: Improving Climate Resilience of Critical Assets

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Highlights

- 1D/2D urban drainage model covering the whole metropolitan area of Barcelona (636 km^2)
- Hydraulic characterization of grated inlets and gullies
- Hybrid model approach to simulate runoff conveying to the sewer system
- Multi-hazards perspective in flooding risk assessment

Introduction

Flash floods stand as one of the most damaging natural disasters for infrastructures and human activities. Climate change projections indicate that these events can become more frequent and intense in several areas of the world during the coming decades (Kundzewicz, 2014). Urban areas, due to their intrinsic characteristics (extensive impervious areas, limited drainage capacity and complex topography), are especially vulnerable to this hazard. In addition, the consequences of a flash flood in cities can be exacerbated by the existing interdependencies between services and infrastructures. In this context, assessing the resilience of critical assets and services in urban and peri-urban areas becomes of great importance to support decision making processes to improve the capacity of local systems to cope with the impacts associated with these events (Russo, 2023). This abstract presents the work that is currently being developed around a complex 1D/2D drainage model with a scope encompassing the whole Metropolitan Area of Barcelona (AMB for its acronym in catalan). The model is developed within the Horizon Europe research project ICARIA: Improving Climate Resilience of Critical Assets www.icaria-project.eu (Grant agreement number 101093806).

Methodology

Case study presentation

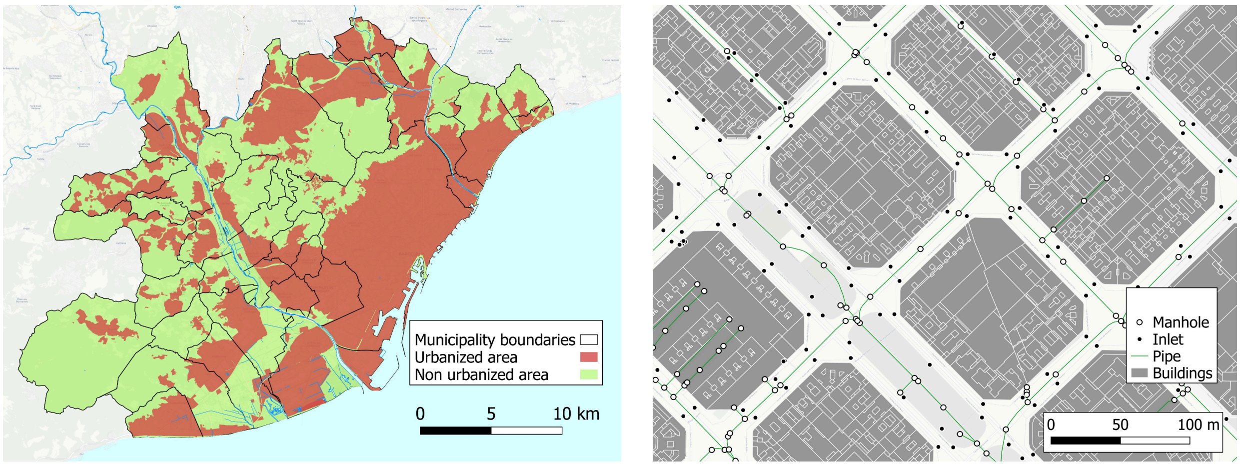
Being the largest conurbation in the western mediterranean, the AMB is home to 3.3 million people and covers a total area of 636 km^2. It is responsible for one half of Catalonia's GDP and stands as the major business and tourism hub for the region. As any other coastal urban area in the Mediterranean basin, the AMB is frequently affected by extreme rain events that often cause flash floods in urban areas. Its yearly average rainfall is around 600 mm, but it is not rare that 50 % of the annual precipitation occurs during two or three single rainfall events. This situation is expected to be exacerbated in the coming decades as a result of climate change (Rodríguez, 2014; Llasat, 2016; Monjo, 2023).

Model setup

The drainage model developed for the AMB is based on a 1D/2D coupled approach (where the 2D domain represents surface water flow and the 1D domain simulates the pipe flow). Unlike other drainage models (e.g. 1D, 2D, 1D/1D), coupled 1D/2D models avoid the oversimplification of the complex reality of urban environments and stand as the more realistic way to simulate the interaction between the drainage network and the urban surface. Despite its heavy computational requirements, this approach is the best option to determine the extent and the risk associated with flooding events in urban environments as results represent the flow depth and surface flow velocity in the affected area (Henonin, 2013; Pina, 2016).

The routing of runoff to the drainage systems in this model is based on a hybrid approach as it represents this process in a realistic manner. Hence, the runoff generated is treated differently based on the kind of area where it is generated. On one hand, the runoff generated in building areas (e.g. roofs, terraces, courtyards) is directly conveyed into the drainage system as each built parcel is directly associated to a specific point in this network. On the other hand, for previous areas (e.g. parks and natural areas) and urban impervious surface (e.g. streets, sidewalks, squares, etc.), which do not correspond to buildings, surface runoff is computed to simulate its transport along the city surface of the model (2D domain) until it enters the 1D domain through the surface drainage system (mainly composed by grated inlets). Importantly, storm water inlets have an essential role in urban drainage allowing runoff to be introduced into the sewer systems according to the design assumption and ensuring safety conditions for pedestrians and vehicles during wet weather conditions (Russo, 2020; Evans 2023). Furthermore, they do not only enable the runoff entry points to the underground drainage infrastructure, but they are the point (together with manholes) through which sewers overflows occur in case of pressurized pipes. So, grated inlets are the key elements that regulate the flow transfer between the 1D and the 2D domains of the model and, for this reason, they need a proper hydraulic characterization. Despite their major importance, the simulation of these critical elements in large scale urban drainage models is often overlooked. Lack of information about inlets hydraulics, its typology, location and a poor representation of the secondary drainage network are usual constraints faced by model developers.

The AMB drainage model (see Figure 1) includes these elements in order to achieve a more realistic modeling of the urban drainage reality of the region. Grate inlets have a wide variety of configurations and designs that determine their runoff interception capacity. This capacity is often expressed as inlet Hydraulic Efficiency, which corresponds to the ratio between approaching and intercepted flow rates (Russo, 2021).



(a) (b)

Figure 1. Depiction of the AMB 1D/2D coupled drainage model showing (a) the total model domain and (b) a detailed representation of the drainage network and its main elements in a section of the model.

Due to the large scale and level of detail of this drainage model, a high computing capacity is required to run simulations in a reasonable time. A high-performance modeling computer is used for this purpose. Its characteristics are detailed in Table 1. So far, preliminary simulations of one half of the model domain have required approximately 40 minutes of computing time.

Table 1. Characteristics of the computer used for running the AMB drainage model

Component	Characteristics
Operating System (OS)	Windows 11 Pro 64 Downgrade Win 10 Pro 64 High End
Central Processing Unit (CPU)	Intel Core i9-12900 2.40G 30MB 16 cores 65W
Computer memory (RAM)	64GB (2x32GB) DDR5 4800 UDIMM ECC Memory
Graphics Processing Unit (GPU)	NVIDIA RTX A4000 16 GB FH Blower Fan 4DP PCIe x16 Graphics
Solid-State Drive (SSD)	HP Z Turbo 2TB PCIe-4x4 2280 TLC M.2 SSD

It is worth noting that the presented model does cover a large metropolitan area with a great level of detail. In this sense, this model is a step forward in bringing together the modelization of urban drainage at regional scale with a highly detailed representation of the sewer system. The table below shows the characteristics of 1D/2D drainage models that have been developed for the city of Barcelona in former research projects.

Table 2. Other regional large scale 1D/2D drainage model

Model domain	Model extent (km^2)	Inhabitants in the domain	Number of manholes	Total pipe length (km)	Computation time	Reference
Half of Barcelona municipality with focus on Raval district	1,1	48.300	3.625	234	7 minutes	Project CORFU (Velasco, 2016)
Barcelona municipality	101,4	1.650.000	40.000	1.650	30 minutes	Project RESCCUE (Russo, 2020)
Barcelona Metropolitan Area	636,3	3.300.000	135.000*	5.800*	90-120 minutes *	Project ICARIA (Russo, 2023)

* Estimated value

Multi-hazard perspective

As it is highlighted in Ali (2022), a part form pluvial flooding, coastal flooding associated with storm surges and sea level rise stand as another major threat for Mediterranean coastal areas. Furthermore, the multi-hazard risk assessment perspective (assessing the risk derived from the simultaneous occurrence of storm surges and extreme rainfall affecting the same region) is gaining relevance due to its importance in holistic risk assessment (Ward, 2022). In this context, it is relevant to remark the occurrence, in January 2020, of Gloria Storm, a compound event involving coincident storm surges and extreme rainfall that caused significant tangible and intangible damages in the AMB (Sanuy, 2021). In order to address this challenge, the 1D/2D drainage model is coupled with a hydrostatic sea level model to provide an innovative approach to assess how the interaction between pluvial and coastal flooding can lead to greater impacts. This coupling is based on defining boundary conditions to the drainage model that represent a higher water level in the water receiving bodies. This fact can constrain the draining capacity of the sewer system due to the intrusion of seawater through its outlets causing a “backwater” effect. Furthermore, this multi-hazard perspective enables a more comprehensive risk assessment of events where low-lying coastal areas are affected by floods resulting from combined storm surges and extreme rainfall.

Flood risk assessment at regional scale

The main output of the drainage models will be the mapping of flow velocity and water depth in the Barcelona Metropolitan Area. In the context of project ICARIA, these results will be coupled with sectoral impact models that will support a comprehensive assessment of the tangible direct and indirect impacts of pluvial floods on services and critical assets of the AMB (e.g. properties, transportation, electricity distribution network, waste management services, wastewater treatment plants). Furthermore, the assessment of intangible impacts associated with risk for pedestrians and vehicles will also be considered. Importantly, the specific vulnerability and exposure of risk receptors will be taken into account following the risk-based risk assessment approach proposed in the IPCC’s Sixth Assessment Report (AR6) (Russo, 2023).

Results and discussion

The model presented in this abstract is now under development and final results are expected to be reached during the first semester of 2024. The main outputs of such a model will be maps of flow velocity and water depth in the Barcelona Metropolitan Area for extreme rain events corresponding to different climate change scenarios and associated to several return periods.

Firstly, the results will enable identifying the major flood prone areas in the region as well as determining highly exposed critical infrastructures. Such information will permit identifying weaknesses in urban drainage systems at local and regional scale. Secondly, the coupling between the output of the drainage model and sectoral models will help quantifying tangible (direct and indirect) impacts in monetary terms in critical assets and services. Furthermore, other impact models focused on intangible direct impacts on people will also be implemented to assess the risk for the population during flash flood events. Finally, the model will stand as a tool to evaluate the capacity of specific adaptation measures to (1) reduce extension and severity of floodings in the AMB, (2) minimize their impacts on specific assets and services, and (3) reduce the risk exposure of citizens. In addition, in liaison with the sectoral tangible impact models, it will be possible to monetize the benefits of implementing specific adaptation strategies.

The AMB drainage model goes beyond the assessment of risk associated with pluvial flooding by incorporating a multi-hazard perspective. In this sense, conditions associated with coastal flooding (e.g. extreme sea level) that can constrain the performance of the urban drainage system are included as boundary conditions for the model.

Conclusions and future work

A large-scale 1D/2D coupled drainage model is developed for the Barcelona Metropolitan Area, covering 636 km^2 and 36 municipalities. It is based on a hybrid approach to realistically simulate the routing of surface runoff to the sewer system and incorporates the location and characteristics of grated inlets.

Its results will support the risk assessment of pluvial floods for a number of critical assets and services, also under simultaneous storm surge and extreme rainfall conditions. This model will also serve as a tool to assess the climate resilience of these assets against floods and determine cost effective measures to improve their coping capacity.

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