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Assessing the sensitivity of pluvial flood modelling to the topographic description of Urban Areas

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Abstract
As the effects of climate change continue to unfold, pluvial flooding has become a significant concern. While the development of complex models for simulating pluvial flooding events has advanced, challenges related to input data persist. In this research we want to assess the sensitivity of flood models to the level of detail in the description of the topography at small scales. The case study presented below examines a portion of a neighbourhood in Genoa, where cases of pluvial flooding are frequently reported.

Highlights
- The input data availability issue, with specific focus on the spatial resolution, is addressed by means of a comparison of pluvial flooding scenarios using different resolution of digital terrain and surface models.
- Pluvial flooding scenarios will be modelled using the HEC-RAS 2D software.

Introduction
The incidence of pluvial flooding events, driven by climate change and the accelerated urbanisation process, has heightened communities' vulnerability to flood-related hazards. Urban expansion exacerbates these issues by reducing soil permeability and altering natural watercourses, thereby intensifying the severity of flooding events and affecting a larger population. Pluvial flooding has thus emerged as a critical area of concern.
Despite advancements in the development of complex models for simulating pluvial flooding events, challenges associated with input data remain pervasive. These issues can be broadly categorized as follows:
- Data Availability and Integration: Urban flooding involves multiple interconnected systems, and a significant challenge lies in obtaining precise and comprehensive data on urban drainage systems, which includes various kind of information such as topographical details and hydraulic characteristics. Furthermore, integrating data from diverse sources and ensuring interoperability across various data formats and platforms increase the complexity *(Luan et al., 2023; Bulti & Abebe, 2020*).
- Data Acquisition and Homogeneity: Continuous data acquisition with consistent instrumentation is essential, as interruptions or inconsistencies in data collection may compromise the accuracy and reliability of flood models and decision-making processes. (*Bartos & Kerkez, 2021*).

- Data Quality, Accuracy, and Uncertainty: Data sourced from different platforms are susceptible to random errors, biases, and inherent uncertainties. Rigorous validation and calibration techniques are critical to improving the reliability of flood model outputs and the overall effectiveness of flood management strategies (*Sañudo et al., 2024; Luan et al., 2023*).
- Spatial and Temporal Resolution: Urban flooding dynamics are influenced by a wide range of spatial and temporal variables, including rainfall intensity, land surface characteristics, and the hydraulic conditions of drainage networks. Acquiring data with sufficient spatial and temporal resolution remains challenging, as conventional datasets often lack the necessary granularity. This deficiency contributes to uncertainties in flood modelling and predictive analyses (*Sañudo et al., 2024; Chang et al., 2015*).

All the issues described above can affect various types of input data (sewer system, precipitation, terrain description…), with varying degrees of specificity. In particular, this study investigates the impact of varying resolutions and level of details described by Digital Terrain Models (DTM) and Digital Surface Models (DSM) on the accuracy and performance of pluvial flood simulations in urban environments. The proposed experimental methodology integrates geospatial data processing with 2D flood modelling to examine how the resolution, level of detail, and quality of DTM and DSM datasets influence the outcomes of flood simulations. The connection to the subsurface drainage network, at this point, is disregarded because the focus of this work is on the terrain description and the actual data from the sewer system are not recently updated by the Municipality of Genoa and the water management company.


Fig.1 Area case of study, in Sampierdarena district

Materials and methods

The case study is a densely built urban area within the Metropolitan Area of Genoa, Italy, which is frequently affected by pluvial flooding caused by rainfall events characterized by a low return period (below 5years). The urban area under investigation is in the western part of Genoa, specifically in the Sampierdarena district, and includes a flat zone covering approximately 1 km² [see Fig1].

Data acquisition and preprocessing

Digital Terrain Model (DTM) and Digital Surface Model (DSM) datasets are used to accurately capture the topographic and surface characteristics of the terrain. These datasets are sourced from the Ligurian Region or the City of Genoa and are processed and prepared using QGIS, a widely used open-source geographic information system (GIS) software.

The resolution of the datasets used range from high-resolution data (sub-meter, 50 cm) to coarser resolutions (several meters, e.g., 5 m) to assess the role of spatial resolution and data fidelity in flood simulation accuracy [Fig2]. The preprocessing stage ensures that the data are co-registered and converted into formats compatible with the chosen hydrodynamic simulation software, HEC-RAS 2D. Additionally, adjustments, modifications, and detailed refinements (see below for details) are made to the DTM and DSM to enhance their suitability for simulation purposes.

Integration into HEC-RAS 2D

After preprocessing, the DTM and DSM datasets have been imported into HEC-RAS 2D to simulate pluvial flooding, using the Rain-on-Grid (RoG) methodology. HEC-RAS 2D is a widely used hydrodynamic modelling tool capable of simulating both riverine and urban flooding, including pluvial events caused by intense rainfall. The RoG method is commonly used in hydrological and environmental studies to simulate the effects of rainfall on a grid-based landscape. It involves modelling the flow of water through a grid system in response to precipitation, making it valuable for flood forecasting, watershed management, and hydrological simulations. (*USACE, 2025; Costabile et al., 2021*).

This method operates on a grid representation of the terrain, where the landscape or watershed is represented on a regular grid. Each cell in the grid represents a small portion of the area, capable of storing and transfer runoff. The grid allows for a detailed analysis of how rainfall interacts with the environment. Additionally, the precipitation input, obtained spatialising point measurements, is applied to each grid cell. This data, which is often obtained from weather stations or radar measurements, can vary across grid cells depending on location and rainfall pattern. Initially, a synthetic event is used as input; in particular a Chicago hyetograph is computed (0.5-h duration, time-to-peak equal to 0.5 and T=5 and 10 years) using the Depth-Duration-Frequency curve referring to the regional studies on the extreme precipitations of Liguria (DG ARPAL 77/2019).
The runoff is modelled by the RoG model separating it from the amount of water each grid cell retains (infiltration) and simulating the flow into neighbouring cells.

HEC-RAS 2D with RoG module is employed to model surface water flow, considering both the terrain and surface features represented by the DTM and DSM. The DTM is used to define the bare ground surface, facilitating the representation of flow pathways and elevations for hydraulic modelling. The DSM, on the other hand, includes above-ground structures such as buildings, trees, and other urban elements, which influence flow dynamics by creating barriers, altering runoff patterns, or providing localized storage for surface water. The interaction between the DTM and DSM enables a comprehensive simulation of surface water behaviour in urban environments, where land cover is often heterogeneous and complex.
To validate this methodology and assess its effectiveness on results, additional factors will be considered, including the presence of walls within urban areas or the existence of bridges in the city [Fig.2c].

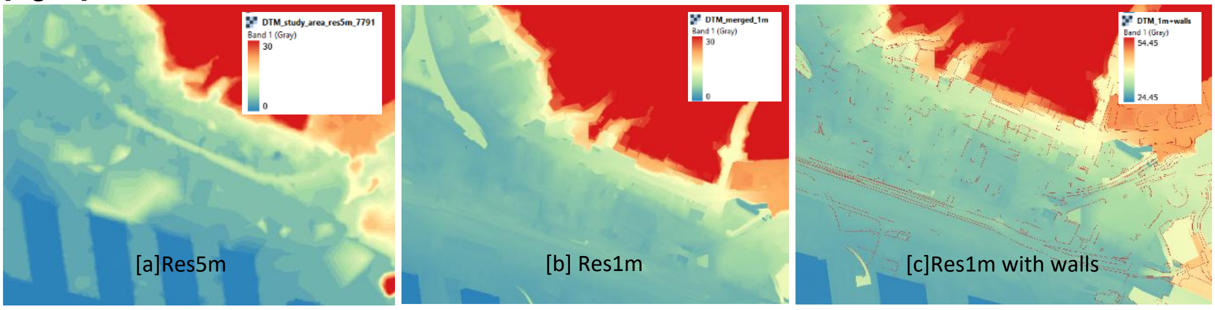

Fig2: Different DTM resolution and detail of walls integrated

Experimental Design: Resolution and Detail Variability

The core of the methodology lies in the systematic variation of the resolution and surface detail of the DTM and DSM datasets. The following parameters are considered to explore their influence on the flood simulation results:

- Spatial Resolution: Datasets with varying grid cell sizes (0.5 m, 1 m, and 5 m, see Fig. 2) will be tested. High-resolution datasets are expected to capture finer terrain variations, potentially enhancing model accuracy, but may increase computational time and resource demands. Conversely, coarser datasets may simplify calculations but could omit finer features that influence runoff pattern.
- Level of Detail: The datasets will be manipulated to include or exclude certain urban features, such as small buildings, vegetation, and anthropic structures such walls or barriers to surface flows. By comparing simulations with different levels of surface detail, the study will evaluate

the effect of urban features on pluvial flood propagation and flood mapping, including their influence on runoff rates and localized flow patterns.

Results Analysis and Evaluation

The analysis of the simulation results focusses on the following key performance metrics:

- Flood Extent and Depth: The influence of DTM and DSM resolution on the predicted pluvial flood boundaries and water depths is examined. Higher-resolution data is hypothesized to produce more accurate and localized flood extents.
- Hydrodynamic behaviour: The study assesses the variation in flow velocities, inundation patterns, and water accumulation areas under different model configurations. This analysis highlights how the presence of detailed urban features in the datasets influences the behaviour of surface water during pluvial events.
- Computational Efficiency: The computational performance, in terms of processing time and memory usage, is evaluated for different data resolutions and levels of detail. The trade-off between simulation accuracy and computational resources will be explored to identify optimal modelling strategies.
- Model Accuracy: The overall accuracy of the model, as compared to real-world pluvial flood data, is evaluated for each combination of DTM and DSM resolution. In particular, the percentage differences in the maximum depths, maximum extent, and maximum velocity is analysed and compared. This performance is assessed with respect to a previously defined synthetic rainfall event, rather than a real event. This analysis will provide insights into the degree to which different data characteristics and resolutions impact the reliability of pluvial flood predictions.

Conclusions and future work

This experimental methodology will provide a comprehensive framework for assessing the influence of varying DTM and DSM resolutions, levels of detail, and data quality on pluvial flood simulations in urban areas. By systematically varying these parameters, the study aims to identify the most appropriate datasets for accurate and efficient pluvial flood modelling.

The findings of this research will contribute to the refinement of urban flood risk assessments, informing decision-making for flood mitigation and management strategies in rapidly urbanizing areas. Furthermore, the methodology will provide guidance for balancing computational efficiency with the need for high-resolution and detailed input data in hydraulic modelling workflows.

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