PLUVIAL FLOODING SCENARIOS USING RAIN GAUGES AND OPPORTUNISTIC SENSORS FOR AN URBAN CASE STUDY

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KEY POINTS

- *The input data availability issue, with specific focus on the spatial resolution, is addressed by means of a comparison of pluvial flooding scenarios using rain gauges and opportunistic sensors.*
- *Pluvial flooding scenarios were modelled using the HEC-RAS 2D software.*
- *The relevance of the input rainfall pattern on pluvial flooding scenarios is highlighted for a specific case study characterized by a rapidly evolving event with a limited spatial coverage.*

1 INTRODUCTION

The occurrence of pluvial flooding events, attributed to climate change and the rapid urbanization process, has accentuated the susceptibility of communities to flood-related hazards. Urban expansion intensifies the issue by diminishing soil permeability and changing natural watercourses, amplifying the severity of flooding incidents and impacting a larger population. Pluvial flooding, often exacerbated from inadequate stormwater management systems, now commands significant attention.

It is essential to emphasize that despite the intricate nature of the model crafted for simulating events, the input data consistently pose a challenge. Indeed, data related issues can be categorized as follow:

- *Data availability and integration:* urban flooding involves multiple interconnected systems. One of the primary concerns pertains to the accessibility of precise and exhaustive data concerning urban drainage systems, encompassing infrastructure arrangement, topographical details, land utility, and hydraulic characteristics. Integrating data from diverse sources and ensuring interoperability between different data formats and platforms can be complex. (*Luan et al*, 2023; *Bulti & Abebe*, 2020).
- *Data acquisition and homogeneity:* ensuring the continuity of data acquisition, with consistent use of the same instrument, is paramount, as interruptions or gaps in data collection can compromise the accuracy and reliability of flood models and decision-making processes. Thus, the implementation of robust maintenance schedules, backup power systems, and redundant sensor networks can help mitigate the risk of data loss and ensure the continuous availability of critical information for urban flood management even if this operation presents logistical and operational challenges (*Bartos, M. & Kerkez, B.,* 2021; *Di Baldassarre et al,* 2009).
- *Data quality, accuracy, and uncertainty:* data collected from various sources may be subject to random errors, biases, and uncertainties. Rigorous validation processes and calibration techniques enhance the reliability of flood modelling results and improve the overall effectiveness of flood management strategies (*Sañudo et al*, 2024; *Luan et al*, 2023).
- *Spatial and temporal resolution:* urban flooding is subject to the influence of diverse spatial and temporal variables, including rainfall intensity, land surface attributes, and the hydraulic conditions within the drainage network. Nevertheless, procuring data at requisite spatial and temporal resolutions can prove challenging. Conventional data may lack the necessary granularity, thereby fostering uncertainties in flood modelling and predictive analyses (*Sañudo et al*, 2024; *Chang et al*, 2015).

In the present work the input data availability issue, with specific focus on the spatial resolution, is addressed by means of a comparison of pluvial flooding scenarios using rain gauges and opportunistic sensors for an urban case study.

2 MATERIALS AND METHOD

Due to the limited extension of the urban catchment areas, with a high density of buildings and largely impervious surfaces, rapidly evolving pluvial floodings are typically experienced in cities resulting from the inefficiency of the urban drainage system in terms of the hydraulic failure of the storm water pipes and/or the insufficient capacity of the storm drain inlets. In the Mediterranean region, this is accompanied by a rainfall climatology characterized by short-duration and high-intensity events, which typically show a quite limited spatial extension and very rapid evolution, therefore hard to be captured by the traditional monitoring networks. Since the storm water drainage in the urban texture is structured in a great number of small-size catchments, usually smaller than the typical spacing of rain gauge stations, urban catchments are often ungauged. In this section, the case in which a rain gauge station is available within the investigated catchment area is considered, together with the possible alternatives in case of ungauged basins including other contiguous rain gauges and opportunistic sensors.

The development of opportunistic sensors is a recent innovation in the measurement of precipitation intensity (*Giannetti & Lanza*, 2023), suggesting a high potential for large-scale application due to the low cost of their installation and operation. The Smart Rainfall System (SRS) was developed at the Polytechnic School, University of Genova, as a cooperation between the Department of Civil, Chemical and Environmental Engineering (DICCA) and the Electrical, Electronics and Telecommunication Engineering and Naval Architecture Department (DITEN) to estimate rainfall intensity in real time by processing the attenuation of microwave satellite link signal measured by low-cost sensors (*Federici et al*, 2014). The SRS infers the rainfall amount or intensity by interpreting the extra attenuation induced by the precipitation on the received signal level over a fixed trajectory (link) spanning few kilometres and this may happen to improve the representativeness of the measurement with respect to point scale rain gauges.

The case study of the present work is a densely built urban area within the Metropolitan area of Genoa (Italy), that was recently (September 24th, 2022) affected by pluvial flooding associated with a rainfall event characterized by a low return period (T between 1.5 and 3 years). The investigated urban area is in the West part of Genova, in the Sampierdarena district, and is characterized by a flat zone of about 1 km^2 (see red area in Figure 1a). It is equipped with a traditional tipping-bucket rain gauge station (named Arpal-FI) managed by the environmental protection agency of the Liguria region (ARPAL) and one SRS (named SRS-SA). Two further SRSs are available close to the investigated area: in Borzoli (named SRS-BO) and in Castelletto (named SRS-CA) positioned 2.7 km and 4.0 km far from Arpal-FI, respectively. In the analysis other two rain gauges managed by ARPAL are considered, the Castellaccio (Arpal-CA) and Centro Funzionale (Arpal-CF) located at 5.1 km and 4.5 km far from the Arpal-FI. The position of each instrument is shown in Figure 1a. Measurements from the ARPAL rain gauges are available at 5 minutes resolution while SRSs provide measurements at 1 minute resolution.

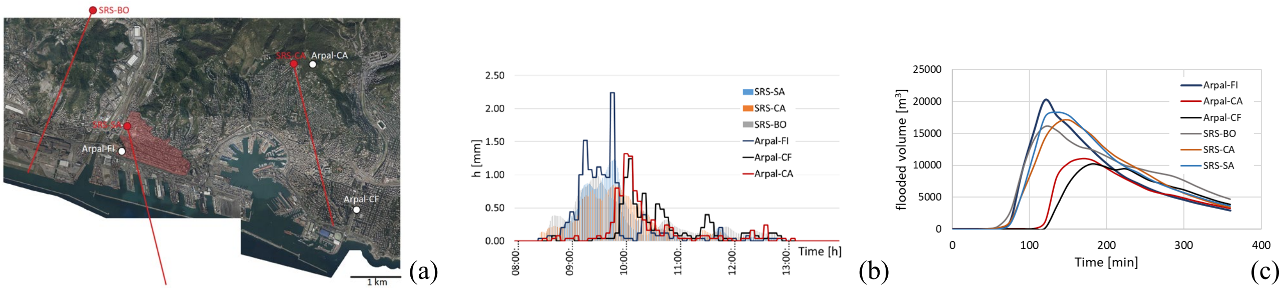

Figure 1. (a) overview of the investigated urban area with indicated the position of the three rain gauges (white circles) and the three SRSs (red circles) with the associated links (red lines), (b) temporal evolution of the investigated rainfall event as measured by the various sensors, (c) temporal evolution of the modelled flood volume (conditional on a minimum water depth h = 5 cm) obtained when using as input the rainfall measurements from various sensors.

Assuming the Arpal-FI rain gauge as the reference instrument for the present study (since it is located within the investigated urban area) the ratio between the rainfall amount measured by each instrument and the reference one, as well as the peak ratio, are summarised in Table 1. The comparison of the investigated rainfall event as measured by each instrument is shown in Figure 1b. It is evident that the two Arpal rain gauges positioned outside of the study area do not capture the magnitude and the duration of the rainfall event measured at the reference station. On the contrary, the SRSs, despite some underestimation of the peak rainfall, provide a good representation of the temporal evolution and total volume of the reference rainfall event. This can be ascribed to the larger spatial representativeness of the SRS with respect to the traditional rain gauge.

The satellite link may indeed cross the bulk of the rainfall event even though the precise location of the sensor is not immersed in the rain field.

Pluvial flooding scenarios were modelled based on the rainfall measurements obtained from the various sensors using the HEC-RAS 2D software (*USACE* 2021), solving the shallow water equations (SWE-EM stricter momentum) at fixed time steps of 0.5s and a mesh size equal to 5m. Spatial information is provided by a high resolution (1m) DTM, where buildings were added using a GIS software. The connection with the subsurface drainage network is neglected in this study since in a companion work *(Chinchella et al*, 2024) it is shown that flooding in the study area is ascribable to a complete clogging of stormwater inlets meaning that the subsurface drainage network is inefficient.

Instrument	Rainfall amount ratio	Peak ratio	Volume ratio condit. on h>5cm	Max Depth ratio
Arpal-CA/Arpal-FI	0.62	0.59	0.54	0.91
Arpal-CF/Arpal-FI	0.64	0.55	0.50	0.91
SRS-SA/Arpal-FI	1.07	0.56	0.90	1.02
SRS-CA/Arpal-FI	1.02	0.38	0.84	1.01
SRS-BO/Arpal-FI	1.08	0.45	0.79	1.03

Table1. Rainfall event and flooding parameters as a comparison with the reference instrument (Arpal-FI).

3 RESULTS

The results of the modelled scenarios are reported in terms of maps of the maximum water depth (see Figure 2) and the ratios between the flooded volume (conditional on a minimum water depth h = 5 cm) and maximum water depth obtained in each scenario and the reference values obtained using the rainfall measured at Arpal-FI (see Table 1). The temporal evolution of the modelled flood volume (conditional on a minimum water depth h = 5 cm) is reported in Figure 1c.

Both the maps and the ratios indicate that differences are limited when SRSs are employed, either when positioned in the same urban area or at few kilometres far from the area. The point nature of measurements taken at rain gauge stations outside of the study area reduces to a half the flooded volume and by 10% the maximum water depth. In all cases a reduction of the extension of the flooded area is shown indicating an underestimation of the flood hazard.

The temporal evolution of the modelled flood volume reflects the differences already observed in the temporal evolution of the rainfall event as measured by the various sensors, including the shift in time of the core of the event in case of the two rain gauge stations located outside of the study area. The significant underestimation of the rainfall peak experienced by the SRS measurements does not result into a corresponding reduction of the peak of the flood volume probably because of the accumulation of flooded water in the depressed areas of the domain.

4 CONCLUSIONS

Various pluvial flooding scenarios were simulated in the present work to highlight the impact of data availability and reliability over the assessment of the flood hazard in a highly urbanised district of the town of Genoa. Significant differences were observed and quantified between flooding scenarios obtained by simulating the distribution of excess rainwater when various rainfall data are considered. A real-world event measured by rain gauge stations and opportunistic sensors is used to compare the results.

Although the overall flooding conditions are captured in all the examined cases, due to the simplification adopted in the flow modelling approach, it is evident from the results that significant differences in the expected flood volumes and maximum water depth are obtained when using various sources of the rainfall information. In the case of the simulated event, the role of opportunistic sensors located within or in the proximity of the study area largely outperforms the contribution of nearby rain gauge data when these are located even only 5 km far from the study area, and this was shown to hold for both the total flooded volume and the maximum water depth.

In this work the relevance of the input rainfall pattern on the modelling of pluvial flooding scenarios is highlighted for a specific case study characterized by a rapidly evolving event with a limited spatial coverage, suggesting that the input information plays a central role even prevailing with respect to details of the flood modelling approach.

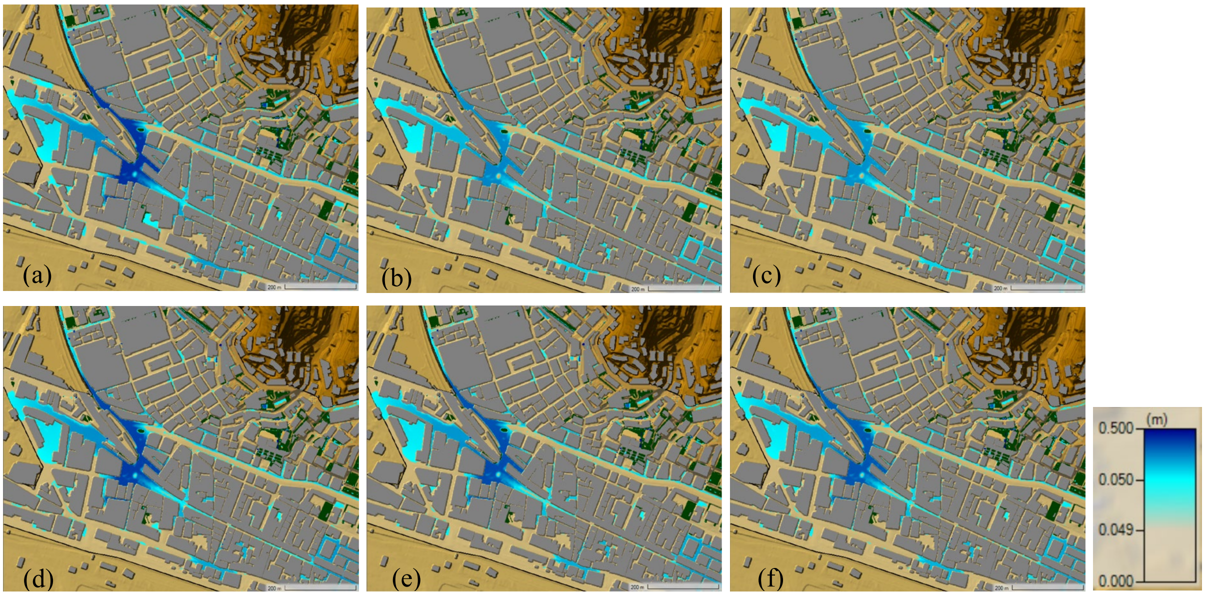

Figure 2. Maps of the maximum water depth for the investigated rainfall event using measurements from: (a) Arpal-FI, (b) Arpal-CA, (c) Arpal-CF, (d) SRS-SA, (e) SRS-CA and (f) SRS-BO.

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