Rainwater harvesting for urban flood management: a modelling framework for sub-catchment scale installations

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Highlights

- The percentage of imperviousness is the limiting factor of the rainwater harvesting effectiveness in urban flood management
- The maximum rainfall intensity and total depth evaluated at the event scale slightly impact the hydrologic performance
- The dimensionless variable called event storage fraction is introduced to describe the rainwater harvesting effectiveness at the sub catchment scale

Introduction

Urban flooding has become one of the most frequent natural disasters in recent years and Low-Impact Development (LID) approach is nowadays recognized as an alternative to traditional grey infrastructure to mitigate the negative impact of urbanization on hydrological processes. Recently Domestic RainWater Harvesting systems (DRWH) have been included among LID solutions since they simultaneously provide the dual benefit of water supply augmentation and stormwater detention as documented in the literature investigated through both modelling and experimental studies (Deitch and Feirer, 2019). The main objective of the present research is to assess the effectiveness of DRWH to support the urban flood management at the sub-catchment scale.

Methodology

The analysis of the DRWH effectiveness is carried out by means of a Decision Support Tool (DST) implemented in the web-gis application namely TRIG Eau (Palla and Gnecco, 2021).

Urban catchment outline

The outline of the urban catchment refers to a non-specific urban area of 2 ha. The area of main roads and residential areas are assigned respectively equal to 0.54 and 1.46 ha, respectively the 27 and 73 percentages of the total area, thus complying with the most common residential settlement characteristics. The percentage of impervious of the main roads is assigned equal to 100% while the one of the residential areas is selectable between the 30%, 45%, 75% and 90% thus describing different urbanization degrees.

The urban area is served by a storm water drainage network consisting of 13 junctions (including the terminal node that defines the final downstream boundary) and 12 conduits located below the streets network. Three different drainage network configurations, namely coastal, medium-slope and high-slope are implemented in the TRIG Eau platform in order to cover the main typologies of plane-altimetric conditions.

Modelling simulations

The hydrologic-hydraulic modelling is undertaken using EPASWMM 5.1.007 (Rossman, 2010). Specific details on DRWH modelling are reported in Palla et al. (2017). Numerical simulations are performed at the event scale including two initial conditions of the systems corresponding to empty or full tanks (Palla and Gnecco, 2021). Modelling scenarios include:

- four degrees of urbanisation: 30%, 45%, 75% and 90% of imperviousness for residential area;
- four climate regimes in the North Mediterranean area, namely Humid Temperated (HuT), Mediterranean Continental (MeC), Hot Temperated (HoT) and Sublitoral (Sub) and three return periods (T= 2, 5 and 10 years)
- three drainage network configurations differing in terms of conduits slope and lengths, namely coastal, medium-slope and high-slope
- a DRWH conversion scenario designed according to the simplified method as indicated in the Italian guideline UNI/TS 11445 (2012).

Results and discussion

The simulation results are examined by means of the well-known hydrologic performance, Volume and Peak Reduction indexes (namely VR and PR, respectively). The indexes indicate respectively the relative differences of total runoff volume and the maximum flow rate observed at the outlet section of the catchment in the reference and the DRWH scenarios (Palla et al., 2017).
The impact of the different factors including the urban catchment configurations (i.e. the drainage network typology, the percentage of imperviousness) and the precipitation regime (i.e. the design total rainfall depth and maximum rainfall intensity) are statistically investigated to point out the effectiveness of the DRWH systems. Results indicate that the percentage of imperviousness reveals the limiting factors in the urban contest of concern. Based on the result of the statistical analysis, the hydrologic performance is examined with respect to the event storage fraction that is evaluated as the ratio between the event runoff volume resulting from the impervious surface in the reference scenario and the storage capacity of the DRWH system. Figure 1 illustrates the behaviour of the hydrologic performance indexes versus the event storage fraction for the 144 simulated scenarios. The event storage fraction allows to describe the trend of the hydrologic performance, revealing a linear relationship in the case of the VR index. Results plotted in Figure 1 shows that a minimum storage fraction value of 0.4 is required to obtain on average VR and PR greater than 0.2.

Conclusions and future work

Finally it can be argued that, for a typical residential catchment in the North Mediterranean area, the DRWH effectiveness in supporting the urban flood management becomes relevant starting from a storage event fraction of 0.4 that means realizing storage tanks able to contain at least the 40% of runoff volume generated by the targeted event. Future works concern the introduction of innovative "smart systems" operating schemes (Di Matteo et al., 2019) in order to minimize the storage volume required to obtain the desired hydrologic performance.

References

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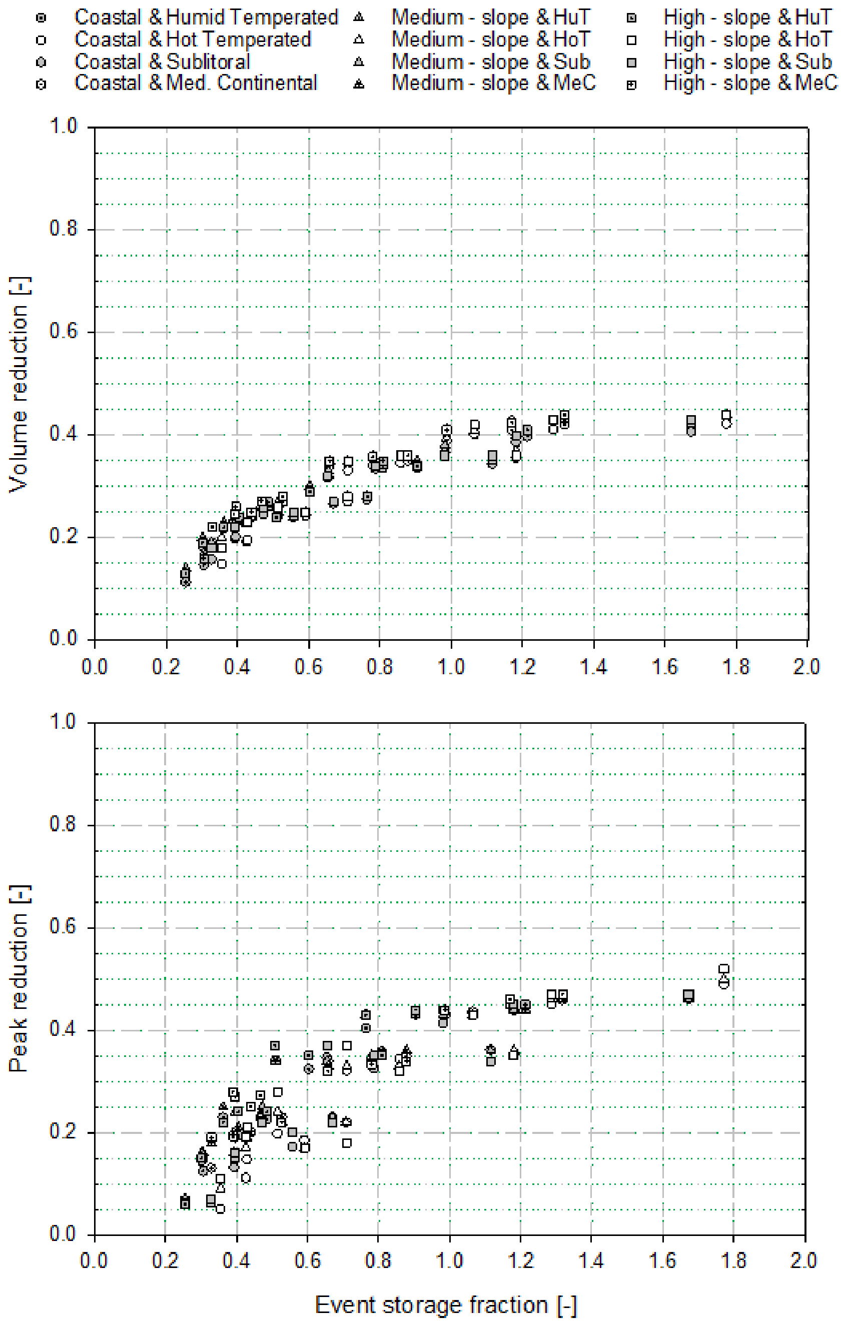

Figure 1. Volume and peak reduction indexes plotted versus the event storage fraction simulated for the three drainage network catchment typologies (Coastal, Medium–slope; High-Slope) according to the four precipitation regimes (Humid temperated, Hot temperated, Sublitoral and Mediterranean continental).