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ATTI DEL CONVEGNO

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PLANNING NATURE-BASED SOLUTIONS FOR URBAN STORMWATER MANAGEMENT

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KEY POINTS

- *We assess the potential of different (combinations of) NbS typologies to reduce urban flood hazard in the Trento municipality.*
- *Results show the potential of combined NbS techniques to reduce flood hazards, however we found a slightly decreasing effectiveness while moving towards very extreme events.*

1 INTRODUCTION

Urban flooding is caused by intense rain events that exceed the handling capacity of the sewage network. It is a growing concern for many cities in the world, with serious economic implications (Sörensen and Mobini, 2017). On the one hand, climate change is causing an increase in rainfall frequency and intensity in several regions across the world. On the other hand, urban expansion and increasing soil sealing reduce the amount of infiltrated stormwater, putting additional pressure on the existing pipes (Miller and Hutchinson, 2017). Urban flooding is therefore a coupled hydrologic-hydraulic problem, which needs to be analysed and addressed considering both land covers and soil characteristics, and the conditions of the underground sewage network.

Within this context, sustainable urban water management is advocated as a paradigm shift where hard infrastructure solutions are combined with sustainable urban drainage systems that mimic and contribute to restore the natural water cycle (Adem Esmail and Suleiman, 2020). An example of sustainable urban drainage systems are nature-based solutions (NbS), which leverage the capacity of ecosystems to provide multiple environmental, social, and economic benefits. Among the NbS most frequently adopted to reduce flood risk are installing green roofs, desealing parking areas, and creating infiltration ponds and rain gardens (Rosenberger et al., 2021). Beyond reducing peak flows and runoff volumes, NBS may provide additional benefits in terms of water quality and security, and contribute to microclimate regulation, habitat provision, and aesthetic quality, among others (Cortinovis et al., 2022).

However, planning NBS for urban flood risk reduction is a complex task that requires to consider multiple factors, with limited possibility to learn from previous experiences (D'Ambrosio et al., 2023). In fact, locally specific factors play a major role in defining the spatial distribution of the risks and the potential impacts of the proposed solutions in each context. Coupled hydrologic-hydraulic models such as SWMM, with the possibility to simulate different NbS scenarios, can support the assessment of alternative options considering specific local conditions as well as different rain events (Pappalardo et al., 2017). The aim of this study is to assess the potential of different (combinations of) NbS typologies to reduce urban flood risk in a highly sealed urban context in northern Italy.

2 MATERIAL AND METHODS

Trento is an alpine city of around 120,000 inhabitants in northern Italy. Its climate is semi-continental, with cold winters and hot summers (a maximum of 35°C from June to August) and average yearly precipitation of 900 mm. The study area is located in a valley floor in the northern part of the city and covers 409.43 ha. It was selected due to the high concentration of impermeable surfaces, as it includes the main commercial and industrial districts, along with some residential areas. The prevalent soil types are C and D (2), which exhibit moderately high and high runoff potential respectively.

The dynamic rainfall-runoff simulation model Storm Water Management Model (SWMM) was used to simulate stormwater quantity using single event simulation. SWMM dynamic flow routing model is applied, which solves the complete 1D Saint-Venant flow equations and Curve number method for accounting the infiltration were applied. The drainage network's sub catchments, conduits, and outfalls were extracted using a QGIS plugin and a 2 m resolution lidar based digital terrain model. The final network setup consists of 397 subcatchments which consider their own type of land use, conduits and junctions, and 12 outfalls that drain into adjacent waterways (the Adige and Lavisotto rivers) and water canals. The required SWMM inputs for each component of the drainage network were extracted from the SWMM manual, and the curve numbers were estimated using the infiltration values (mm) of the corresponding land cover types with the specific soil type (e.g. Ross et al., 2018; Del Giudice et al., 2014). A statistical analysis of extreme precipitation has been applied to the data downloaded from the Meteotrentino website. The Trento (Laste) station was chosen as the raingauge, as it is the active one closest to the study area analyzed and with the greatest number of data available. A constant rectangular hyetograph was applied with precipitation varying for duration (15, 30, 45, and 60 minutes) and return period (20, 50, and 100 year). Using these design parameters, the peak discharge in each conduit was estimated based on the 15 min rainfall data of a 20-year return period rainfall event. The design diameters were defined by adopting the Gauckler Strickler equation, setting an optimal degree of fullness as 80%. The corresponding maximum and minimum diameters were 1.8 m and 0.2 m respectively. The choice to test the network for rainfall events with return periods higher than the one used for the design allow us to explore the impact of nature-based solutions on urban flood hazard in extreme weather conditions (e.g. Zhang et al., 2021).

This study analyzed two NbS types: green roofs and permeable parking. Green roofs are composed of layers of soil to support vegetation, with a special drainage mat to enhance temporary ponding and drainage of excess rainwater (e.g. Bai et al., 2019; Chui et al., 2016; Palermo et al., 2020). Permeable parkings are pavements with gravel, grasses and porous or bituminous concrete, purposely designed to infiltrate rainwater and filter pollutants (6,7,9,10). The main parameters of the adopted NbS are taken from previous studies (i.e. Bai et al. 2019; Chui et al., 2016; and Rosenberger et al., 2021) and from the SWMM Manual. For the implementation of green roofs, we considered both the roof areas of every potential building (85.12 ha), and the roof area of industrial buildings only (29.64 ha). The latter provide a flat surface convenient to install green roofs and were identified based on the land use map. Regarding the permeable parking, we integrated the information of the public parking areas from the land use map with the available parking lots close to the industrial buildings (16.45 ha in total).

To explore the impact of a progressive implementation of the NbS scenarios, the analysis was conducted stepwise, considering end-member scenarios, by increasing the areas of NbS by 10% from the reference scenario (i.e. no NbS) to the full implementation scenario. Moreover, combined scenarios were designed considering 16 possible combinations of the two NbS (i.e green roofs exclusively on industrial buildings and permeable parking) applied with increasing intervals of 25% from 25% to 100% implementation. The simulations to measure the impacts of the scenarios considered 15 min rainfall data with 50-and 100-year return periods. Three criteria have been chosen as indicators to compare the scenarios: (i) the quantity of runoff from the sub catchments, (ii) the peak volume reduction, and (iii) the degree of fullness of the conduits. We considered average values of the 12 outfalls.

3 RESULTS

Since the drainage network was built using a design rainfall of 15-minute duration and 20-year return period event (i.e. reference scenario), the findings of a 50-year return period simulation show that they can withstand the effects of heavy storm events with no flooded nodes and just 1% of the conduits surcharged. However, 37% of the nodes experienced flooding during storm events with a 100-year return period, and 40.6% of the conduits surcharged. These indicate a need for NbS interventions to relieve some of the drainage network's stress that extreme events may cause.

Considering a stepwise implementation from 10 to 100%, installing green roofs on the all-available buildings would reduce the peak flow from 4.3% to 43.2% and the runoff volume from 4.3% to 44.1% for storm events with a 100-year return period. However, this efficiency decreased when the available area was limited to the 29.64 ha corresponding to industrial buildings. In this case, even when 100% available space is converted to green roof, the peak decrease and runoff volume for 100-year return period storm event are only 12.2% and 15%, respectively. Figure 1 shows the spatial distribution of the runoff volume created from each sub catchment for both the reference (current) scenario and the 50% and 100% implementation of green roofs on the industrial buildings. The comparison reveals a notable drop in runoff volume in those specific subcatchments where the buildings are located. However, the average values at the outfalls also take into account subcatchments with no NbS intervention, which results in a significant reduction of efficiency when limiting the available area to green roofs to 29.64 ha.

Figure 1. Spatial distribution total runoff volume for each subcatchments

The same analysis is conducted using 15-minute rainfall event with a 100-year return period and implementing a variable percentage of the available area, from 10% to 100%, to be devoted to permeable parking (instead do green roof). Results yielded peak flow and runoff volume reduction values 0.96% to 8.6% and from 0.95% to 6.6%, respectively.

For the combined scenarios considering the two NbS (green roofs on industrial buildings and permeable parking) implemented with increasing intervals of 25% from 25% to 100%, the reduction in peak flow and runoff volume were evaluated under 3 storm events (Fig. 2). The finding revealed that all the combinations perform better for less intense storm events. Specifically, the combination scenarios AD (25% PP & 100% GR), BD (50% PP & 100% GR), CD (75% PP & 100% GR), and DD (100% of both NbS) demonstrated the most effective performance for both water quantity indicators, arranged in increasing order. These results indicate that the water quantity reduction efficiency of NbS decreases as the intensity of the storm events increases for the same short duration.

4 DISCUSSION AND CONCLUSIONS

The study focused on quantifying the effect of NbS implementation over a urbanized area of the city of Trento. The work focused on i) the drainage network design and ii) the quantification of the effect of different NbS solutions scenarios on urban flooding hazard reduction. Three different extreme rainfall events have been considered of 20, 50 and 100 year return period, respectively. For the 100 year return period event, while increasing the percentage of installed green roof from 10 to 100% a reduction of the hydrograph peak and volume has been found, ranging from ~4 to ~40%. The same experiment based on permeable parking provided a reduction of the hydrograph peak and volume ranging from ~1 to ~8% on average.

We also assessed the effect of combined green roof and permeable parking NbS increasing their percentage from 25 to 100% by 25% increments. Results confirm the potential of these techniques to reduce flood hazards in urbanized environments, being a valuable strategy to reduce both flow peak and volume. However, the effectiveness (i.e. reduction in hydrograph peak and volume) decreases while moving from 20 to 100 year return period rainfall events. Those results are consistent with previous studies (e.g. Ercolani et al., 2018; Liu et al., 2014). The use of combined NbS practices may not only results in better hydrological/hydraulic performances but could also be easier to promote through diversified urban planning mechanisms and policies. Future work will be devoted to a more accurate analysis in terms of i) economic assessment/cost benefit analysis of the analysed scenarios and ii) the quantification of their hydraulic effectiveness in a changing climate.

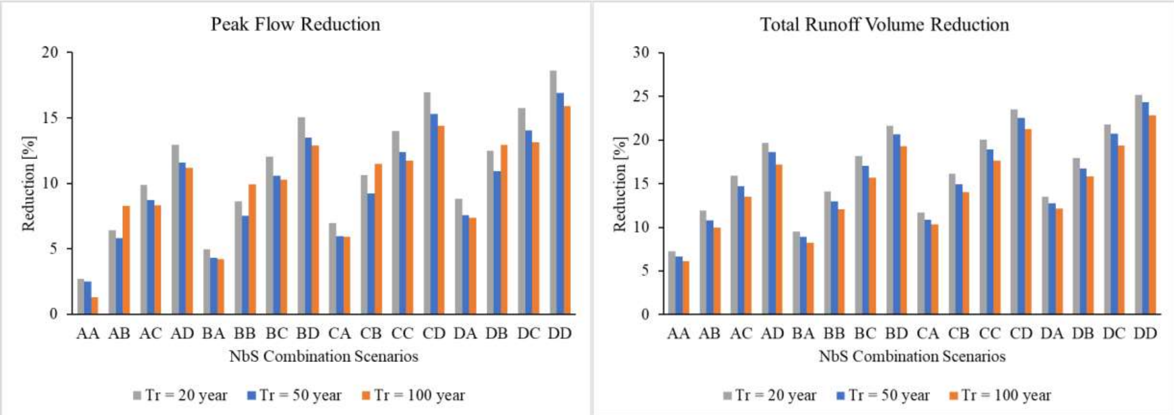

Figure 2. Performance of NbS combined scenarios in a) peak flow reduction and b) total runoff volume reduction at precipitation of 15 min duration with 20, 50 and 100 years return period. The NbS combinations AA, AB, AC, AD, BA, BB, BC, BD, CA, CB, CC, CD, DA, DB, DC, DD indicate combined percentages of Green roofs increased in 25% intervals from 25% to 100% with an interval of while the permeable parking kept 25% and the same way till the 100%.

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