Nature-based Adaptation to Address Climate Change-related Flooding:
Insights on an Italian Coastal City

# Nature-based Adaptation to Address Climate Change-related Flooding: Insights on an Italian Coastal City

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|---|---|
| **Keywords** | nature-based solutions, pluvial flood, biophysical assessment |
| **City Population** | 29,513 |
| **City Area** | 33.7 km$^2$ |
| **City GDP** | 1 billion USD |
| **Climate Zone** | Csb (warm summer Mediterranean) |
| **ARC3.3 Linkage** | Nature-Based Solutions: Enhancing Capacity to Respond to Shocks and Stresses |



**Introduction.** As one of the most evident consequences of climate change, cities are becoming increasingly vulnerable to weather extremes. Although direct climate change impacts are limited to temperature extremes and sea level rise, changes in flooding features and other hydrometeorological hazards are associated with climate change processes, leading to higher probability and severity of these events (IPCC, 2019).

Coastal urban areas are highly vulnerable to compound flooding due to the combined effects of storm surge, sea-level rise, and increased runoff during heavy precipitation, which exacerbate overall impacts. (Hirabayashi et al., 2013; Pfahl et al., 2017; Vousdoukas et al., 2017; Bevacqua et al., 2019). Specifically, urban (or pluvial) flooding is related to the runoff exceedance in respect to the drainage system capacity of the cities during short duration and intense rainfalls (Miller and Hutchins, 2017; Costa et al., 2021).

Surface water management (as Nature-based Solutions strategies) has been proven as the more adaptive way of facing climate change instead of building larger sewer systems. Over the last decade, the role of Nature-based Solutions (NbS) has been proposed to support climate adaptation rather than traditional "grey" strategies (as hard infrastructures) which can temporarily withstand climate variabilities (Frantzeskaki et al., 2019).

Indeed, NbS are flexible and multifunctional strategies in the face of climate change uncertainty while providing a positive impact on humans' well-being and a wide range of ecosystem services (European Environmental Agency (EEA), 2012; Voskamp et al., 2021). NbS represent a practical attempt to strengthen the resilience and adaptive capacity of vulnerable cities. The approach is considered as one of the nine key actions recognized at the UN Climate Action Summit in 2019[1].

NbS are based on the sustainable management, conservation, and restoration of ecosystems, as part of a comprehensive adaptation strategy that considers social, economic, and cultural benefits for local communities (Seddon et al., 2020). In this framework, NbS directly contribute to the reduction of vulnerability of ecosystems, with positive outcomes in all three dimensions (exposure, sensitivity, and adaptive capacity). In this view, increasing awareness about NbS co-benefits by proving their effectiveness promotes willingness to accept such solutions and thus helps their integration into traditional planning (Quagliolo et al., 2022).

The peculiar morphology of Liguria region (northwest Italy) causes very localized precipitation that in some cases is limited to single cities (Paliaga et al., 2019; 2020). In recent centuries, many Italian and Mediterranean cities have experienced increasing vulnerability and heightened flash flood risk.

This situation is particularly notable in the case of small catchments: i) soil permeability reduction; ii) artificialization of drainage networks; iii) loss of natural spaces due to the uncontrolled urban sprawl and land-use changes both in floodplains and at basin scale. For these reasons, the Liguria region has historically been hit by numerous flooding events.

In general, Liguria is a typical case in which urban sprawl seems to have the most decisive role in flooding events (Faccini et al., 2015). In the recent decade, in the period between 2000 and 2019, a range of catastrophic events occurred in Italy and specifically in this area (Paliaga et al., 2020).

In November 2014, another flooding event strongly impacted Liguria, especially the area of Levante, from Genoa to Rapallo. In the inland part of Rapallo municipality, landslide risk isolated the area. In October 29th, 2018, the Vaia storm hit the coastal area of Rapallo causing the destruction of the tourist port and the flooding of the city, in particular affecting the lowland near the shoreline (Bompani and Origone, 2018; Pedemonte et al., 2018).

[1]https://www.un.org/en/climatechange/climate-action-coalitions

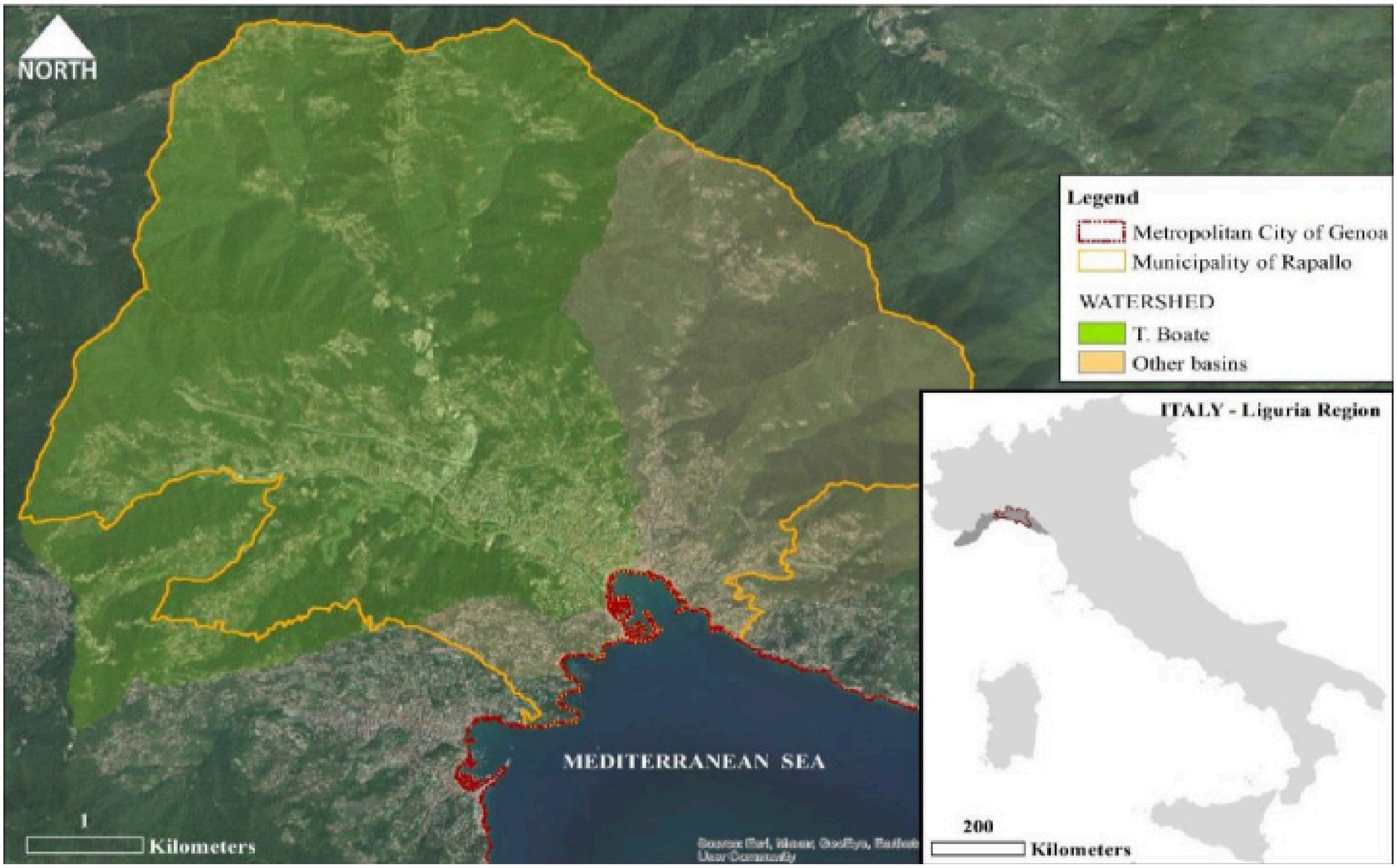


**Figure 1.** *Study area (from Quagliolo, Comino and Pezzoli, 2021).*

**Analysis, Evaluation, and Implementation.** Based on the aformentioned risks, the region stood to benefit from a performance-based assessment of NbS that aims to mitigate the impacts of pluvial flooding. To this end, a spatial biophysical evaluation of NbS implementation was developed by conducting a flood risk assessment through the employment of the InVEST Urban Flood Risk Mitigation (UFRM) model combined with Geographic Information System (GIS). NbS scenarios of green roofs and rain gardens for a design storm of a 10-year return period typical for the Liguria region have been performed for the case study of the coastal city of Rapallo. These kinds of rainfall events are usually more frequent and thus most damaging each year.

First, the most flooded areas in terms of flood depth were identified using the UFRM model, which is part of the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) software (version 3.9.2) developed by the Natural Capital Project[1]. Second, the NbS scenario impacts have been simulated through the UFRM model by evaluating the tangible benefits of such solutions in terms of flood reduction. The elaboration of model inputs and outputs is conducted through the employment of QGIS 3.16 software[2]. The final spatial index has been elaborated through GIS tools to provide a picture of the greatest flood-prone areas by testing where the NbS interventions prove higher benefits. This method helps define quantitative runoff reduction targets to be integrated into ecological calibrated urban planning (Liu et al., 2017; Kadaverug et al., 2021).

The UFRM spatial model focuses on cities' capacity to reduce flood depth during extreme rainfall and flash flooding events. Although biophysical quantification of runoff in built environments is difficult, due to factors such as sewer systems and soil moisture conditions affecting water discharge, the model addresses this challenge through empirical simplifications (Quagliolo et al., 2021; Salata et al., 2021).

The main assumption considers flood-prone areas as a result of the interaction between the permeable-impermeable surface layers (i.e., land use type) and soil drainage (related to the soil characteristics), which generates the runoff during rainfall events (Sharp et al., 2020). Table 1 shows the data needed for the InVEST-UFRM modelling.

Even though the EU Flood Directive (2007/60/CE) is lacking quantitative flood risk reduction targets or proposed methodologies for NbS implementation, the results from the base scenario simulation (pre-NbS) provide a quantitative reduction target while setting the scene to prioritize the suitable areas for NBS implementation. The definition of these two NbS-scenarios (NbS-1 and NbS-2 ± presented in Figure 2) was developed under the Piano Nazionale di Adattamento al Cambiamento Climatico (PNACC - 2017), which

[1]Available at https://naturalcapitalproject.stanford.edu/software/invest
[2]Available at https://www.qgis.org/en/site/forusers/download.html

| Data type | Data description | Data Source (year) |
|---|---|---|
| Administrative boundaries layer | Area of interest. | Created from Geoportal Liguria (2019) |
| Rainfall amount value | Total rain for a single storm event of 10-years return period (91 mm for 1 hour of rainfall). | ARPA Liguria (2013) |
| Land Cover raster | Land cover shows the surface coverage. | Generated from two databases:<br>- Geoportal Liguria (2019)<br>- SINANET (2015) |
| Hydrological Soil Group raster | HSG represents the saturated hydraulic conductivity of soils (Ksat mm/h). | Generated from two databases:<br>- Landscape Units – Geoportal Liguria (2000)<br>- Profili e Trivellate – Geoportal Liguria (2000) |
| Biophysical table | Table connecting the land use classes with each HSG. | Adapted from USDA - United States Department of Agriculture (2004) |

**Table 1.** *InVEST Urban Flood Risk Mitigation model inputs*

identifies 21 key actions among various sectors synthesized in four main fields: hydrogeological instability, coastal area management, biodiversity, and urban settlement (Ministero dell'ambiente e della Tutela del Territorio e del Mare, Direzione Generale per il Clima, 2017). The NbS-scenarios definition follows the Cloud Burst action plan of the Local Resilience Strategy - Genova Lighthouse through the Urban Agenda Genova 2050.

**Results and Discussion.** Results for the scenario without the implementation of NbS (base scenario) show that the flood depth per pixel increases with higher urbanization level (Figure 3). Indeed, this representation gives a more detailed overview by identifying the strong positive correlation between flooded areas and the sealed surfaces. To consider the future implications in terms of adaptation policies, the model output was futher processed in GIS to obtain flood indicator values at neighbourhood level. These final estimates represent a mean value of flood depth distributed on the entire neighbourhood which allows comparisons and prioritization of the intervention areas at city scale (see Figure 3).

Results for flood depth reduction due to NbS-1 and NbS-2 show variations within three central neighbourhoods of Rapallo in which green roofs and rain gardens are simulated (Figure 4). At city level, the flood depth reduction improves by 14% due to NBS-1 and 7% because of NBS-2. The largest flood depth reduction occurs for the NBS-1 scenario, with a difference of 7% compared to NBS-2.

**Future Implementation and Concluding Thoughts.** This research, performed through spatial analysis and modelling

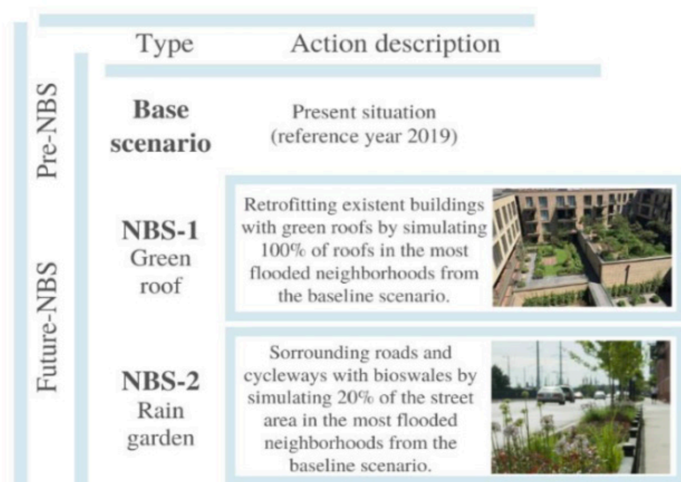


**Figure 2.** *NBS scenarios design (from (Quagliolo, Comino and Pezzoli, 2021).*

approaches in a quantitative perspective, intends to contribute improving the knowledge needed to support urban planning for climate resilient cities, as well as a more comprehensive understanding about the relation between climate change and NbS. Studies such as this research are important as they strengthen the knowledge to essentially act as a foundation for urban climate change adaptation planning. The application of this method proves the potential of a locally adapted holistic approach to assess NbS biophysical impacts of urban flood risk. Due to the lack of monetary valuation of environmental resources, NbS still lack their development and integration into urban adaptation planning.

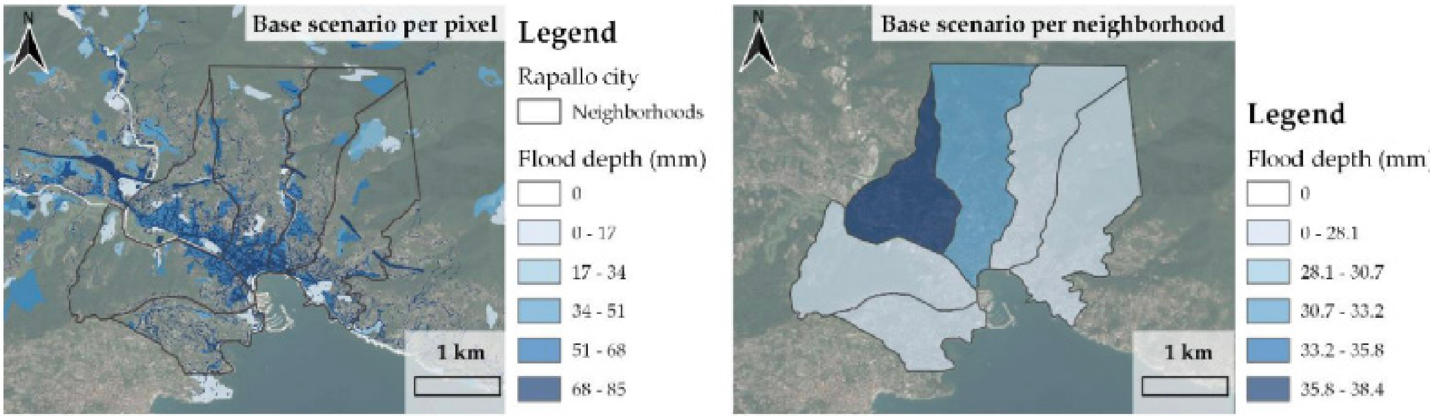


**Figure 3.** *Flood depth (mm) under 10-year return period as mean value per pixel and neighbourhood for the city of Rapallo.*

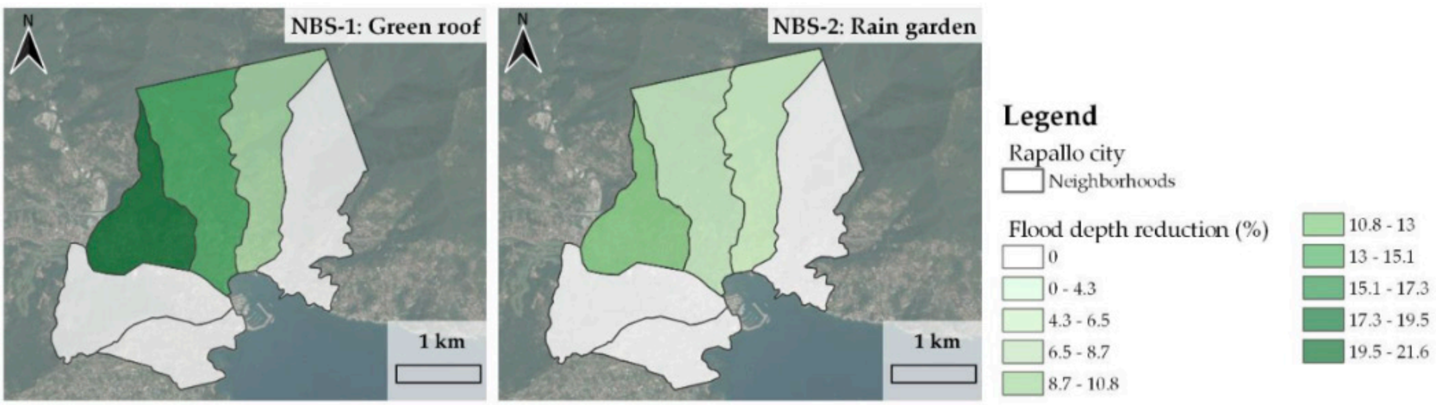


**Figure 4.** *Green roofs and raingardens percentual differences of flood depth reduction under 10-years return period per neighbourhoods for the city of Rapallo.*

Therefore, results could be improved by integrating a cost-benefit analysis of NbS implementation, particularly considering the economic savings from flood damage reduction and other non-monetary benefits. To finally mainstream the operationalisation of the NbS into urban planning, different categories of interventions linked to the criticalities of simulated scenarios may be defined (as direct interventions of private or indirect interventions of the public sector).

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**Additional Data**

- **Population Density:** 861 people/km$^2$
- **Per Capita Gross National Income (GNI):** 61,620 USD (High Income) [2024]
- **Gini Coefficient:** 34.3 [2023]
- **Human Development Index (HDI):** 0.915 (Very High) [2024]
- **Type of Climate Intervention:** Adaptation

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