DAYLIGHTING RIVERS
SCIENCE EDUCATION FOR CIVIC ECOLOGY

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Daylighting Rivers: Inquiry Based Learning for Civic Ecology

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Edited by
Ugolini F. & Pearlmutter D.

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PLANNING NATURE-BASED-SOLUTIONS THROUGH GEOGRAPHIC INFORMATION TOOLS TO MANAGE FLOOD RISK ON FLORENCE CITY ENVIRONMENT

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Abstract
The growth of impervious surfaces due to an exponential and uncontrolled urbanization, the evolution of socio-economic scenarios and the impacts of climate change have made the urban/peri-urban areas weaker against pluvial-flood risk (e.g. issues related to the correct management of the secondary river network, criticalities associated to culverted or covered rivers). Innovative strategies to make urban/peri-urban environment more resilient and sustainable are needed and Nature Based Solutions (NBS, i.e. actions inspired or supported by nature) can play an important role to provide integrated responses to the environmental, social and economic future challenges.
In this context, the aim of the FLORENCE (FLOod risk and water Resources management with Nature based solutions on City Environment) project is to explore the effectiveness of NBS for the flood risk management of the City of Florence (Italy).
The project is based on a quantitative evaluation methodology supported by geographic information tools that clarifies the benefits and co-benefits of NBS, highlighting their limitations and exploring the possible synergies with existing infrastructures.
First, a GIS based analysis has been made in order to map Ecosystem Services (ES) priority areas, analysing the main ES supply and demand. This analysis is coupled with the identification of the constraints (regulatory, urban planning, economic, environmental, social) to realize a multicriteria zoning of Florence urban environment, highlighting the potential areas for NBS implementation. Lastly, the selection of suitable NBS and their hydraulic modelling is carried out in the identified areas. This allows the evaluation of NBS performances and the identification of the scenarios that best respond to the city's green development needs.

Keywords: Flood risk, Nature based solutions, Ecosystem services, Geographic Information System

Introduction
City environment evolution of many Italian cities has been characterized by the progressive increase in impermeable surfaces that considerably alter the water balance, drastically reducing the volumes of water infiltrated into the soil, thus increasing the surface runoff. These problems, combined with increasingly intense and violent rainfall events due to climate change (Zölch et al., 2017), highlight the necessity of going beyond the classic drainage solutions (i.e. sewer systems) that have often shown their inadequacy to face the complexity of present water management in urban environment (Zhou et al., 2014).
Nature Based Solutions (NBS), i.e. solutions that take inspiration from nature itself for their functioning, are an interesting option when dealing with urban challenges because they provide multiple benefits, integrating water management targets with other environmental, social and economic aspects (EEA, 2015).

Many cities have already adopted this kind of solutions and many others are currently introducing them in planning. This effort towards the introduction of NBS must be supported by tools that help defining strategies for planning and setting the right criteria for NBS implementation.
Recent literature has shown the importance of supporting the uptake of NBS with spatial analysis that can help decision makers identifying suitable areas for installation as well as the necessity of defining the right criteria for NBS design phase (Meerow et al., 2017; Li et al., 2020; Kaykhrosravi et al., 2019).
This work aims at identifying the most suitable areas for the installation of NBS within the Municipality of Florence with the primary target of pluvial flood risk mitigation. The analysis is based on a selection of indicators that are combined through a Spatial Multi-Criteria Evaluation (SMCE) to derive NBS suitability maps that can support local institutions to steer future planning towards NBS implementation.

Methodology

Location of the case of study

The municipality of Florence extends for 102.39 km^2 in the north-east of Tuscany and has a population of 378,839 inhabitants according to the ISTAT census of 2019. The topography of the area is mainly characterized by flat areas where residential, industrial, and commercial areas are located while the remaining hully portion of the territory is mainly dedicated to agricultural areas, olive groves, forests and vineyards. The city is prone to hydraulic problems due to the progressive urbanization and the limits of existing sewer system, especially during short and intense rainfall events, causing pluvial flooding in various part of the city.

Methodology and data used

To identify areas most prone to flooding during pluvial floods that can benefit from NBS installation, a GIS-based multi-criteria analysis is used. Five indicators are used: slope, imperviousness, hydrologic soil group, drainage density of the sewer system and social vulnerability index to flooding. The selected indicators describe the environmental aspects of the area and its socio-economics characteristics that are fundamental in determining the vulnerability and the associated overall risk in the city environment (Martin-Mikle et al., 2015; Li et al., 2020; Kaykhosravi et al., 2019; Meerow et al., 2017). The data used comes from Italian open databases and this allows easy replicability of the work. Data and related sources are shown in Table 1.

Table 1. Data inventory.

GIS layer	Format/resolution	Source
DTM	Raster / 10 m	Tuscany Region - Morphology
Pedology	Vector	Tuscany Region - Pedology
Land Use	Vector	Copernicus Land Monitoring Service – Urban Atlas 2012
Imperviousness	Raster / 20 m	Copernicus Land Monitoring Service – Imperviousness Density 2015
Sewer System	Vector	Publiacqua Spa
Streets network	Vector	Open Data Municipality of Florence

The slope layer is obtained from Digital Terrain Model (DTM) with 10 meters resolution elaborated by the Tuscany Region, using the QGIS software. The map of slope is shown in Fig. 2a. Slope influences the surface runoff and accumulation zones and it is assumed that flat areas are more prone to flooding (Kandilioti et al., 2012).
The Copernicus programme derived product "Imperviousness 2015" with a spatial resolution of 20 m, is used to analyse imperviousness (EEA, 2015). The map of imperviousness is shown in Fig. 2b.
The characteristics of soils play a fundamental role in infiltration phenomena, depending on their texture, and therefore the percentage of silt, clay, gravel and sand present. Soils are classified by the U.S. Department Soils Conservation Service (SCS) into four main groups according to their water transmission capacity in conditions of maximum humidity (USDA, 2009). The lower the infiltration capacity, the greater the amount of surface runoff generated during rain events. The map of the hydrologic classification of soils is made by the Tuscany Region and it is shown in Fig. 2c.

The sewer density indicator is defined as the ratio between the total length of the sewer network within a census area and the extent of the census area itself. The data concerning the plan and characterization of the sewer network are provided by Publiacqua. The map of density of sewer system is shown in Fig. 2d.
Finally, social vulnerability to flood risk is assessed: the response of the population and the built environment to a disaster depends on physical, economic and social factors (Oulahen et al., 2015). For the evaluation of this index, the results of a previous study are used (Pileggi et al., 2018), in which sixteen indicators, divided into six thematic areas, are investigated: ability to react, immigration, access to resources, education, family composition, population and housing. Data for the construction of the indicators were taken from the 2011 ISTAT census and from statistical analyses carried out by the Municipality of Florence. The map of social vulnerability index to flooding is shown in Fig. 2e.

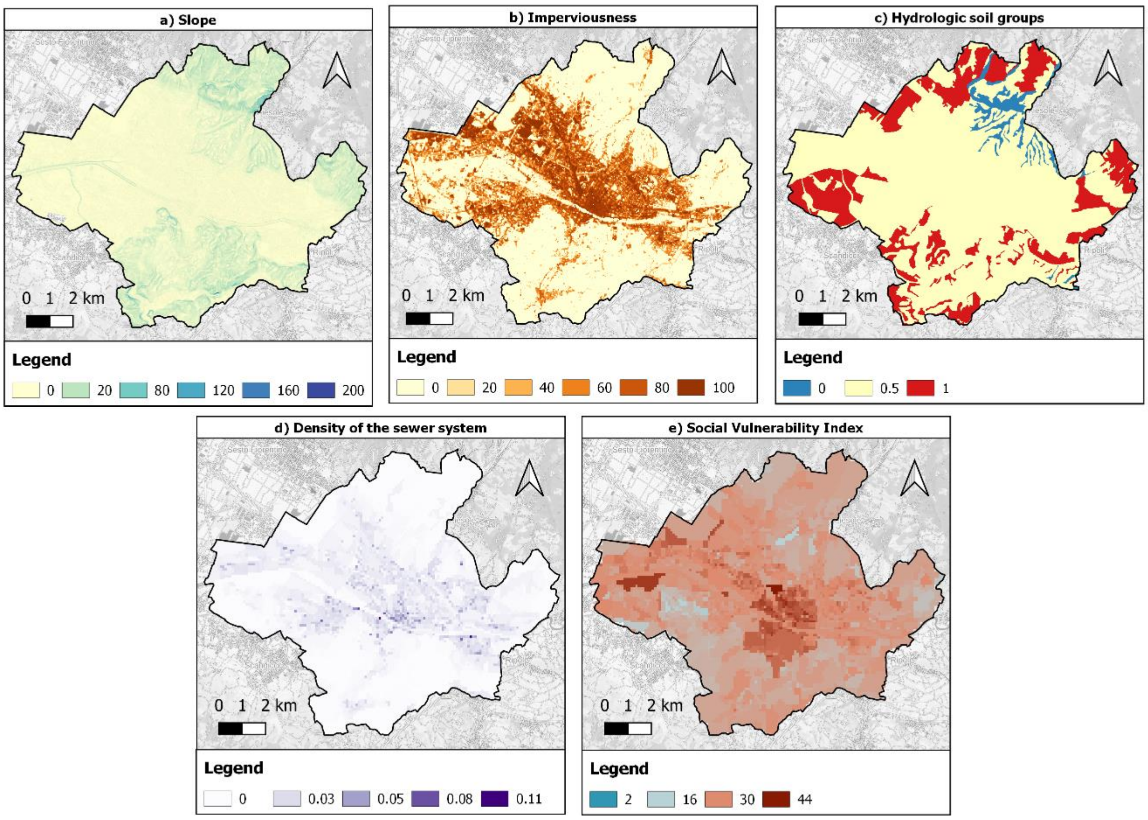

Figure 1. Indicators maps: a) slope, b) imperviousness, c) hydrologic soil groups, d) density of the sewer system, e) social vulnerability index to flooding.

Spatial Multi-Criteria Evaluation

In order to identify the areas with the highest priority in the implementation of NBS for runoff management, a Spatial Multi-Criteria Evaluation (SMCE) is used. In particular, the SMCE module of ILWIS (Integrated Land and Water Information System) software is used to define different types of criteria, according to the contribution they give to the definition of the final map, and to assign a weight to each of these criteria. The criteria are divided into benefits/costs, which respectively contribute positively and negatively to the definition of the final map, and constraints, which identify the areas excluded from the analysis.
Among the used indicators, imperviousness, social vulnerability index and hydrologic soils group are classified as “benefits” with high values identifying areas with high impermeable surface, poorly permeable soils and high social vulnerability. The slope and the density of the sewer system are instead classified as cost with low values identifying areas with a tendency to flood and collect water and a sewer system that is often inadequate for the load.
Two constraints are also defined, i.e. river areas, as areas where no intervention is required, and areas with a slope of more than 10%, where NBS cannot be correctly installed (Jiménez Ariza et al., 2019).

Since each criterion has its own scale of measurement, it is necessary to standardise them to combine them. After standardisation, the weights of each indicators were determined by Analytic Hierarchy Process (AHP) (Saaty, 1987; Kandilioti et al., 2012; Lawal et al., 2012; Gigović et al., 2017; Kazakis et al., 2015; Caprario et al., 2019; Rimba et al., 2017).

Results and discussion

The resulting map identifies the areas that need a higher priority of intervention for the installation of NBS (Fig.2). The map is characterized by values ranging from 0 to 100: zero values correspond to areas excluded from the analysis, while values from 1 to 100 indicate potentially floodable areas. The higher the value, the greater the exposure of this area to flooding.

The highest values are concentrated in the historical centre of Florence and the Rifredi and Novoli districts. Indeed, the historical centre is completely paved with very small green and blue areas. The Rifredi and Novoli districts also have large areas with high levels of imperviousness due to the dense urbanisation of the area. The obtained results are validated by comparing them with the locations of recent flooding due to pluvial extreme events, determined through archive reconstructions of such events.

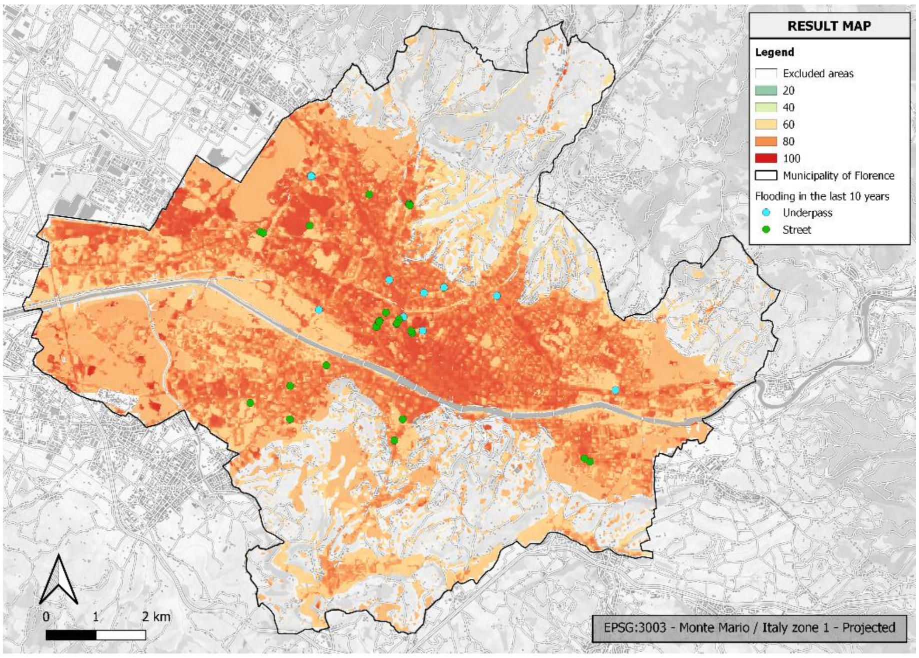

Figure 2. Results map, with values between 0 and 100. Flood events occurred in the last ten years, used to validate the results map, are shown.

Conclusions

Rainwater management in urban environments is one of today's biggest problems: classic grey solutions no longer seem to be appropriate, but solutions inspired by nature, called Nature Based Solutions, have recently widespread, with the aim of restoring the original hydrological cycle as much as possible in pre-urbanisation conditions.

The city of Florence is normally subject to urban flooding during intense rainfall events of short duration mainly due to the high share of impermeable surfaces and the insufficiency of the sewer system. A methodology is developed to identify the urban areas most prone to flooding during rain events, where the implementation of NBS could bring benefits in terms of regulating rain volumes. To identify these areas, a spatial multi-criteria evaluation was used, with environmental and social input data, such as slope, imperviousness, density of the sewer system, hydrologic soil classification and social vulnerability to flooding. These indicators were standardised and

combined, determining the individual weights on the basis of the relevant literature and excluding from the analysis areas with a slope of more than 10% and river areas due to the technical impossibility of realising NBS. The results allow identifying areas where the installation of NBS could mitigate and solve pluvial flood issues.
The map obtained can be of considerable support in territorial planning of the municipality within hydraulic risk mitigation. The same methodology can be used to assess the use of NBS for other purposes, such as reducing urban heat islands, noise or improving water quality.

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