Urban ecosystem services in the planning and design of urban green infrastructure for sustainable cities

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Abstract

Green Infrastructure (GI) represents a network of natural and engineered ecological systems, located at the landscape scale and fully integrated with the built environment. GI provides a wide range of Urban Ecosystem Services (UES) and can enhance the resilience of urban systems to different categories of risk (e.g., hydrological risk and climate change). In particular, two main components of GI are presented and discussed: Non-Urbanized Areas (NUA) and Nature Based Solutions (NBS). NUAs include cultivated land, abandoned agricultural land, grasslands, woodlands and shrubs, often located at the edges of peri-urban cities, and they provide all main categories of ecosystem services. NBSs are techniques developed to control pollution, runoff and, in general, ensure sustainable urban water management, such as green roofs, permeable surfaces, constructed wetlands, retention basins, infiltration basins and filter drains. Ecosystem-service-aware GI planning and design, based on these components, can integrate human activities and the environment, considering both ecological and cultural/social aspects. A methodology for characterizing NUAs is presented as a planning support tool intended to improve current land-use patterns, with the aim of increasing

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the overall supply of ecosystem services in highly dispersed urban contexts. The capacity of GI to control urban stormwater is then discussed through a modelling approach applied to a compact district in the city of Bari.

Keywords

Urban ecosystem services, Green infrastructure, Nature-based solutions

Introduction

Cities grow and shrink, modifying their structure. Common features of urban growth include impervious surfaces, urban sprawl, traffic congestion (Schewenius et al., 2014) and new forms of "peripheralization" of rural areas (Larondelle & Haase, 2013). Conversely, urban shrinkage leads to the creation of empty or under-used urban areas, demolitions, abandoned industrial sites and de-densification (Haase et al., 2014a). All these processes can influence the functioning of an urban system. Every change in land use may alter system equilibrium, with consequences for resilience and system functionality (Pelorosso et al., 2011; 2015).

From an environmental perspective, unregulated development or shrinkage may significantly impact climate, stormwater control, biodiversity, and air and water quality. From a social perspective, several consequences may emerge regarding social capital, segregation, and quality of life.

Planners and designers can limit negative socio-ecological impacts by integrating nature into the city (McPhearson et al., 2014). Nature in cities is fundamental for sustainability. Humans rely on nature to meet primary needs, such as food and drinking water. Nature mitigates negative pressures of an oversized Western society, improves the aesthetic appearance of cities, and green/blue areas reduce the urban heat island effect and flood risks. These areas provide multiple environmental and socio-cultural functions and form part of Urban Green Infrastructure (UGI). UGI improves wellbeing, public health, and provides economic benefits, which can be analyzed through Urban Ecosystem Services (UES) in particular the potential to mitigate the alteration of the hydrological cycle (Leone, Grassini and Balena, 2022). Land-use changes, conversion associated with shrinkage, or residual non-urbanized areas between new settlements offer potential to enhance and expand UGI. Green and permeable elements such as green roofs and trees can also be introduced in compact districts.

Achieving optimal UGI organization is challenging. Sustainability can be enhanced by increasing system complexity, mimicking ecological systems (Ho, 2013; Leone et al., 2017). In cities, this is achieved by considering UGI multifunctionality and spatial organization. UGI should maximize non-dissipative flows and minimize dissipative ones, reducing entropy production. Sustainable UGI depends on designs that reuse system waste and minimize external energy, materials and labor.

A green area may have minor or negative effects if poorly placed. A park in an inaccessible area may not meet needs and requires maintenance resources. The same park could be highly valuable if designed for stormwater management, reducing combined sewer overflows and protecting receiving water bodies. Proper spatial and temporal analysis of environmental and social processes is essential, often requiring GIS and modelling techniques.

This article presents Non-Urbanized Areas (NUAs) and Nature Based Solutions (NBSs) in the context of UES.

Urban green infrastructure (UGI) and urban ecosystem services (UES)

Green Infrastructure describes natural landscape features such as forests, wetlands and waterways. The Landscape Institute (2013) defines UGI as including both green and blue areas inside and outside the city, from country parks and lakes to urban features like green roofs and street trees. UGI supports urban development, nature conservation and public health, providing numerous ecosystem services.

Like built infrastructures, GI provides essential ecosystem services such as air purification, water filtration and cooling, nutrient cycling, soil generation, pollination, climate regulation, carbon sequestration, storm and flood protection, and maintenance of hydrological regimes. Natural lands also provide goods like forest products, wildlife and recreation, serve as habitats, and contribute to the quality of life.

Different methodological approaches exist to assess UES, including monetary and non-monetary evaluation, biophysical models, empirical methods, GIS-based spatial modelling, lookup tables and interviews. The choice depends on available data, resources and project goals.

In this paper, UGI is defined as a network of natural and engineered ecological systems fully integrated with the built environment. It includes NUAs and NBSs, planned at the landscape scale, capable of providing diverse UES and increasing urban resilience.

It also demonstrate the feasibility of land used based to prevent the hydraulic risk by urban planning.

New scenarios for non-urbanized areas (NUA)

NUAs are vegetated areas within urban and peri-urban contexts (La Rosa et al., 2014). They include abandoned industrial areas, agricultural lands, parks, urban gardens, woodlands, vacant lots, cemeteries, sports fields and open spaces. Planners may redesign NUAs to maximize ecosystem services and improve socio-environmental quality.

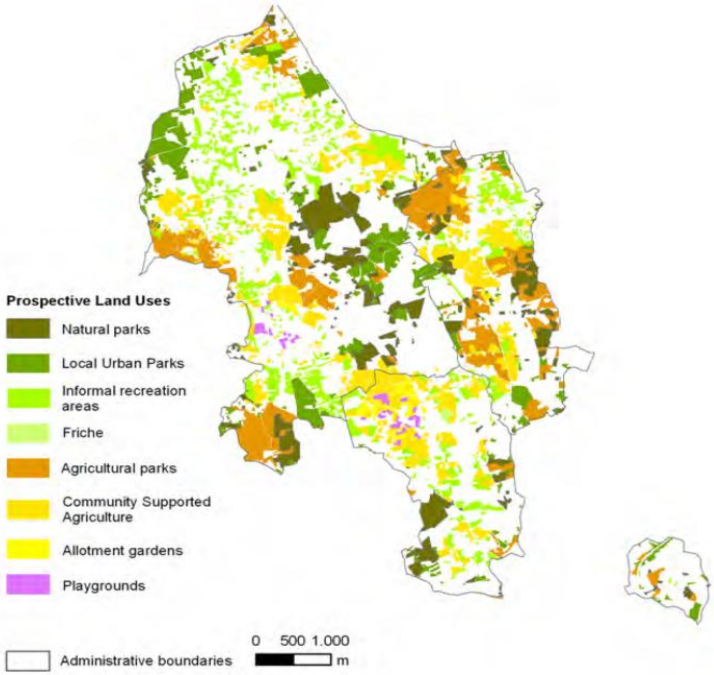

Figure 1 – Example of a new scenario of Land Uses for NUAs

NUAs often act as habitats for flora and fauna. Connectivity between NUAs must be preserved to maintain biodiversity. Due to their vegetation, NUAs reduce heat island effects and stormwater runoff.
A five-step methodology by La Rosa and Privitera (2013) characterizes NUAs:

1. Land-cover mapping
2. Ecological fragmentation index
3. Proximity index
4. Suitability matrix for land-use options
5. Compatibility analysis

This method was tested in three municipalities of the Catania metropolitan area.

Modelling approach for nature-based solutions (NBSs)

Urban regeneration and development can be supported through NBSs designed to manage runoff, pollution and urban water sustainably. NBSs include green roofs, permeable surfaces, constructed wetlands, retention and infiltration basins, and filter drains. Literature sometimes refers to them as SUDS.

NBSs provide ecosystem services even when not explicitly designed for them, such as habitat creation and cooling effects. Multifunctional NBSs can support transitions toward more resilient socio-ecological systems.

Spatial impact evaluation of NBSs requires analysing the territorial context, hydraulic load from adjacent lots, effects on downstream sewer networks, and interactions with other system components. Environmental modelling is an essential planning support tool.

The US-EPA SWMM model simulates stormwater runoff in single events or long-term simulations. It supports scenario evaluation and UES-related indicators.

An example in Bari involved identifying critical sewer nodes, testing different NBS configurations (e.g., 3 to 9 ha of green roofs), and computing an index based on reductions in runoff peak flows.

Conclusions

Cities must become more resilient and sustainable by:
– Increasing system complexity and interactions between natural and human components;
– Reducing ecological footprint;
– Evaluating cultural and social impacts.

Planning should be based on ecosystem-service-aware UGI design. This article presented UGI as a network of natural and engineered ecological systems providing diverse UES and improving urban resilience. NUAs and NBSs were discussed in detail.

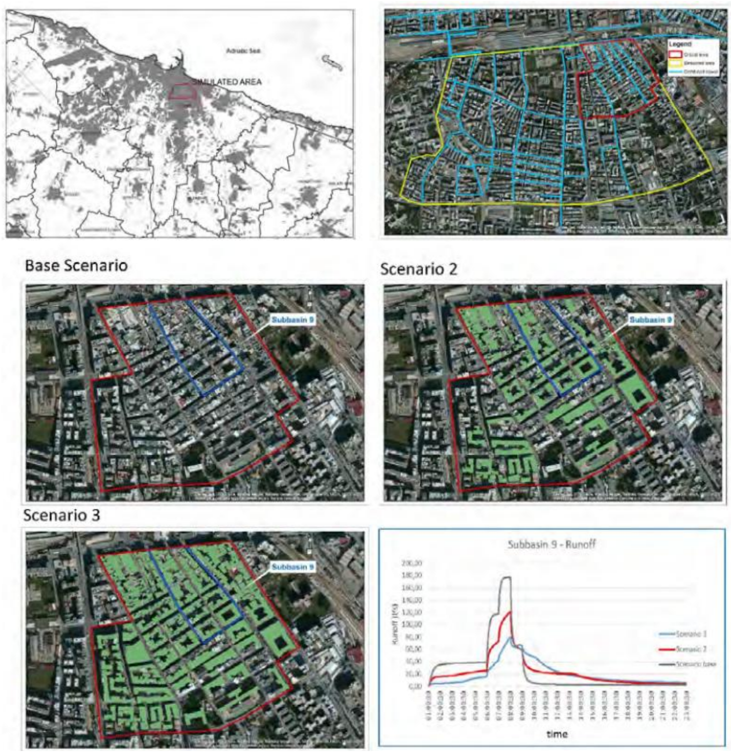

Figure 2 - Scenarios

A methodology for NUA characterization was outlined, as well as a modelling approach for urban stormwater management using NBSs.

The article promotes moving beyond linear engineering approaches toward circular economy principles and territorial engineering, where local resources and closed cycles enhance the socio-ecological functionality of urban systems.

The feasibility of the method is also confirmed by comparing the required 15 hectares of green space (see the graph in fig. 2) with the green urban planning standard, which, according to Italian legislation (D.I. 1444/1968) is equal to 9 sqm/inhabitant.

In fact, the neighborhood examined has approximately 17,000 inhabitants, thus requiring quite precisely 15 hectares of green spaces.

The traditional, structural, solution leads to the restructuring of the sewers, estimated at cost of 30 million euros. The integrated land-use-based approach leads to an integrated green space of 15 hectares.

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