Methodology to Planning Green Infrastructure to Mitigate Landslide Risk

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Abstract. *Green Infrastructures* (GIs) can mitigate the effects of climate change and extreme events that they pose, by managing, for example, the devastating power of floods or landslides, re-establishing spaces and functions. Many tools are available and many more are emerging. The challenge is ensuring that well-planned GIs provide functions which will meet numerous planning objectives.

We propose a methodology for the effective planning of a GIs network that can help public policies. The methodology's application highlights how it is possible to identify the contact points between the protection of ecological integrity and the mitigation of landslide risk, in line with *European Union* (EU) strategies.

Keywords: green infrastructures · ecosystem services · landslide risk

1 Introduction

Green Infrastructure (GI) consists of a network of natural and semi-natural areas strategically planned with other environmental features, designed and administered to provide a wide range of *Ecosystem Services* (ESs) [1, 2], delivering a set of environmental benefits while maintaining and improving the ecological functions [3].

GIs can mitigate the effects of climate change and the extreme events that they pose, managing, for example, the devastating power of floods or landslides by re-establishing spaces and functions [4–6].

In general, the main elements of a GI include parks, private gardens, agricultural fields, hedges, trees, woodland, green roofs, green walls, rivers and ponds [7]. The theme of GIs is closely related to ESs, which are a set of functions naturally provided by ecosystems [8–10] and are fundamental to maintaining the resilience of a territory. ESs are classified by Millennium Ecosystem Assessment (MEA) [11] into four main categories: *Ecological Integrity* (EI), *Regulating* (SR), *Provisioning* (SA) and *Cultural* (SC).

Human-induced climate change, combined with other man-made pressures such as the conversion of soil uses, has altered the functions of ecological systems and has consequently altered the flow of ESs in terms of scale, timing and position.

For decades, European Union (EU) policies have aimed to provide strategies to make Europe more resilient to climate change by ensuring ecosystem-based approaches.

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For instance, the *Seventh Environment Action Programme – 7EAP* (Decision No 1386/2013/EU) was published, which aimed to increase ecological and climatic resilience, so that the restoration of ecosystems and GIs could have significant socio-economic benefits, including public health. Then, in 2011, the *EU Biodiversity Strategy* (COM/2011/244 final) envisaged the restoration of at least 15% of the degraded ecosystems in Europe and aims to expand the use of GIs; this strategy was confirmed by the United Nations General Assembly (UNGA) [12]. In 2013, the *European Commission Strategy on Green Infrastructure* (COM/2013/0249 final) emphasized the important contribution of GIs to the effective implementation of all policies where some or all of the desired objectives could be achieved, at least in part through natural solutions.

To date, the cornerstone for sustainable development is the 2030 Agenda. Since 2016, with its 17 Sustainable Development Goals (SDGs), the Agenda has constituted the new global and universal reference framework for national and international efforts to find common solutions to the planet's major challenges.

In this framework, an important contribution can be carried out by green infrastructures (GIs) that, at all scales, emphasize nature-based solutions (NBS) and the use of local resources and materials to build community self-reliance and resilience. NBS "involve the innovative application of knowledge about nature, inspired and supported by nature" [13].

The document Exploring Nature-based Solutions of the European Environment Agency (EEA) – EU [14], shows the need for GIs to mitigate vulnerability to atmospheric agents, climate change and, in particular, landslide risk.

Soil erosion can cause significant losses in agricultural and forest productivity as it depends mainly on precipitation as well as more surface properties of the soils [15].

According to a study prepared by the EEA, many tests determine how much the increase in landslides is due to climate change. To provide a specific example, forests, along with other vegetation, can reduce the presence of surface landslides.

However, their global increase is indeed due to the excessive use of natural resources and deforestation, as well as increasing urbanization and uncontrolled land use.

2 Objective

Plant cover plays an important role in soil conservation and landslide prevention [16].

Although a large part of European literature has recognized the link between plant cover and slope stability, the ability of GIs to mitigate the risk of landslides is poorly evaluated locally.

Studies show the ability of ESs to mitigate the risk of landslides based on the presence of protective forests and the potential hazard of landslides. Integrating both maps (hazard of landslides and protective forests) involves delineating a potential GIs network to mitigate vulnerability from landslides.

The application of GIs as a protection function can be evaluated.

The aim of this study is to develop a methodology that makes it possible to provide an in-depth description of the procedure outlined in the European document *Exploring Nature-based Solutions* by EEA and translate this into more detailed actions in territorial and urban planning.

3 Materials and Methods

3.1 Methodology

The methodology proposed to achieve this aim is based on a spatial analysis implemented in the GIS environment and consists of three macro-phases:

1) Evaluation of ESs offered by the different types of land use;
2) Identification of land uses that maximize the *ecosystem erosion control* (SRec) service in areas of high and very high hazard;
3) Designing a network that maximizes the multi-functionality of the GIs.

For *macro-phase 1*, a matrix was created to evaluate the capacities of the different types of land cover to provide the ESs.

Several tables in the current literature [17, 18] containing ESs, as defined by MEA, were compared to derive the values for each class of soil according to the EU project *CORINE Land Cover* (CLC).

The different values found in the literature for each ES, which are related to the four macro-categories (EI, SR, SA, SC) according to the land cover type, have been homogenized by performing an arithmetic average operation.

Table 1. Classification of the capacity of different land cover types to provide an individual service.

Level	Capacity
0	No
1	Low
2	Relevant
3	Average
4	High
5	Very high

The values assigned are based on expert evaluations, both conceptual and derived from different case studies and were normalized on a scale of 0–5 (Table 1) [8, 19, 20]. These values can be considered as research hypotheses that need to be tested in further applications.

Concerning the *macro-phase 2*, the methodology provides:

2a) the classification of land uses providing the ecosystem service SRec;
2b) the identification of high (P3) or very high (P4) hazard areas mapped by *Hydrogeological Basin Authorities*;
2c) the intersection between the patches that maximize the SRec service in combination with the high-hazard areas (P3) and very high-hazard areas (P4).

The *macro-phase 3* provides for the design of networks that can connect the patches that maximize the combination of IE and SRec.

3.2 Techniques and Instruments

The analysis implemented in the GIS environment, upon which the methodology is based, refers in detail to the following techniques of spatial analysis: cost-distance, network analysis and map algebra.

The cost-distance analysis is based on the fundamental geographic principle of friction of distance. Two species were analysed, representative of an ecologically homogeneous group, linked to specific habitats: *Sitta europaea* and *Triturus Carnifex* [21].

Two different algorithms were used for the analysis: for *Sitta europaea*, connectivity was evaluated using an isotropic model [22]; in the case of *Triturus carnifex* the use of a simple isotropic model was deemed insufficient. The species' limited ability to move around necessitated a modelling approach that could factor in any geographical obstructions, so an anisotropic model [23] was applied.

The result of the cost-distance models is a raster matrix in which each cell assumes a specific equivalent distance from a target cell class. In the case of isotropic models, the equivalent distance matrix is produced by: a raster image that identifies the target cells; and an impedance matrix that expresses the ratio of impedance of each cell to base cost. Impedance, therefore, acts with the same intensity regardless of the direction of movement. In an anisotropic model, on the other hand, a single impedance matrix cannot represent the forces at play, forces acting differently in different directions.

The impedance value associated with each cell is calculated as:

$$I_e = i^{cos^k \alpha} \tag{1}$$

where:

I_e = resultant value of impedance;

i = modulus of impedance;

α = angle equal to the difference between the direction of motion and the direction of impedance;

k = coefficient; as the coefficient k increases, the function becomes increasingly direction-specific.

The cost-distance analysis was carried out using the Graphab software [24], which is dedicated to modelling ecological networks based on graph theory. It allows for the creation of connections between the same patch types based on the cost-distance by taking into account the type of patches to be crossed or based on the minimum distance between patches. It is then compatible with GIS, through which maps can be modelled to create ecological networks.

The GIS overlay procedure generates a new layer (output level) depending on two or more input layers. The attribute value assigned to each position (e.g. raster or polygon) on the output layer is a function of the independent values associated with that position on the input levels. Two commonly used classes for combining overlays in GIS are *Boolean overlay* (such as AND and OR) and *Linear Weighted Combination* (WLC).

4 Case Study

4.1 Hydrogeological Risk in the Campania Region

The importance of green infrastructures already emerged in Campania in the Rural Development Program (PSR) 2014–2020. Indeed, it is worth mentioning the measure foreseen within the programme "*Creation and/or restoration and/or expansion of green infrastructure and agri-rural landscape elements*" and sub-measure "*Support for non-productive investments related to the fulfilment of agro-environmental objectives*".

The objective of the measure is the sustainable development of agri-food businesses in Campania, providing, where necessary, for the improvement of the environmental conditions of the territory from the agro-climatic point of view.

The Campania Region (Fig. 1), in Southern Italy, has high lithological and geological-structural variability that makes the territory susceptible to different types of landslides. An analysis of the historical events and investments that have affected the Italian territory, and Southern Italy in particular, reveals a lack of knowledge of the places where intervention is called upon [25].

It is ranked second among the Italian regions for the number of victims due to the hydrogeological phenomena. Almost all of these were due to the rapid castings of loose pyroclastic covered by the carbonate masses of the Campanian Apennine and the stone sequences present in the volcanic areas of Mount Vesuvius and the Phlegrean Fields.

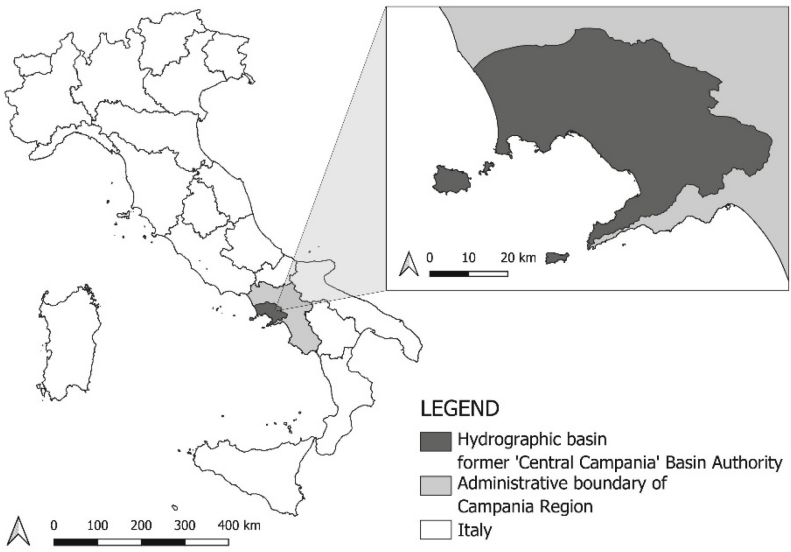


Fig. 1. Geographical framework: Italy with the Campania Region (in light grey) and the hydrographic basin of the former 'Central Campania' basin authority (in dark grey).

The distribution of the hazard from landslides, identified by the *Hydrogeological Basin Authorities*, is highlighted according to the territorialization and use of the soil

expressed as the second level of the CLC legend. In the Campania region, there are 135,800 hectares of land in high hazard (P3) and 131,500 hectares of land in very high hazard (P4). Regarding the P3 and P4 hazardous areas, the wooded areas constitute the most significant land use type (126,279 hectares), equal to 20,5% of the total landslide areas.

However, it should be noted that the application section, refers to the territory included in the former basin authority "Central Campania" because the landslide hazard map was only available for this portion.

5 Application

Macro-phase 1 led to the elaboration of a matrix translated, then graphically, into a series of maps to assess the capacity of different land cover types to provide ESs in the specific case of the Campania Region.

As explained in the previous section, scores, normalized on a scale of 0–5, were associated with each land use according to the CLC classification [8, 19, 20].

Table 2. Percentage of attributing score for each soil cover

Level	Capacity	EI [%]	SR [%]	SRec [%]	SA [%]	SC [%]
0	No	8	8	11	10	36
1	Low	2	33	24	37	3
2	Relevant	2	17	–	53	26
3	Average	49	14	23	–	4
4	High	11	–	11	–	2
5	Very high	28	28	31	–	29

The results (see Fig. 2 and Table 2) show the high capacity of different soil types (forests, swamps, bogs and heaths) to provide a wide range of ESs. Whereas land cover types that have been profoundly modified by man, such as urban fabric, industrial or commercial areas, mines and landfills, have a very low capacity to provide ESs.

For the next macro-phase, the selection of land uses providing the *Regulating Erosion* (SRec) ecosystem service for landslide hazard mitigation was carried out using a geodatabase consisting of information from the Soil Map for Agricultural Use (CUAS) of the Campania Region (2009); while the identification of high (P3) or very high (P4) landslide hazard areas took place after consultation with the Hydrogeological Plan of the Central Campania Hydrogeological Basin Authority (2015) (Fig. 3).

Then, the intersection of the patches maximizing SRec service in combination with the high (P3) and very high (P4) hazard areas was carried out (Fig. 4).

The *macro-phase 3* involves mapping the networks by using cost-distance analysis.

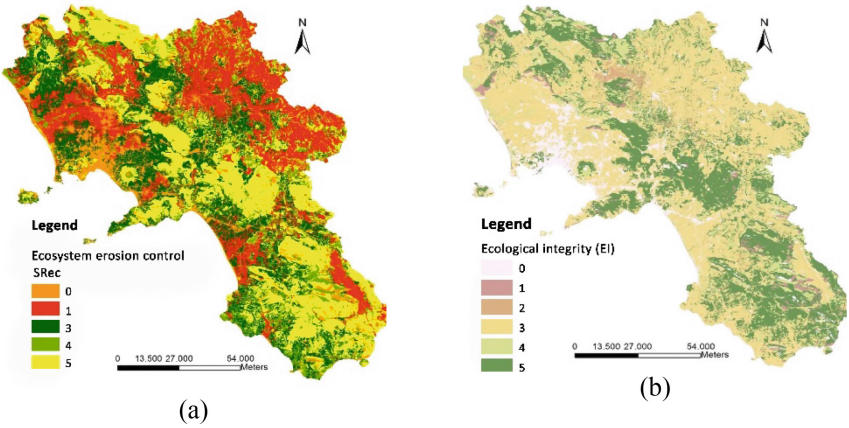


Fig. 2. Scoring based on soil cover: (a) Ecosystem erosion control services map (SRec); (b) Ecological integrity (EI) map

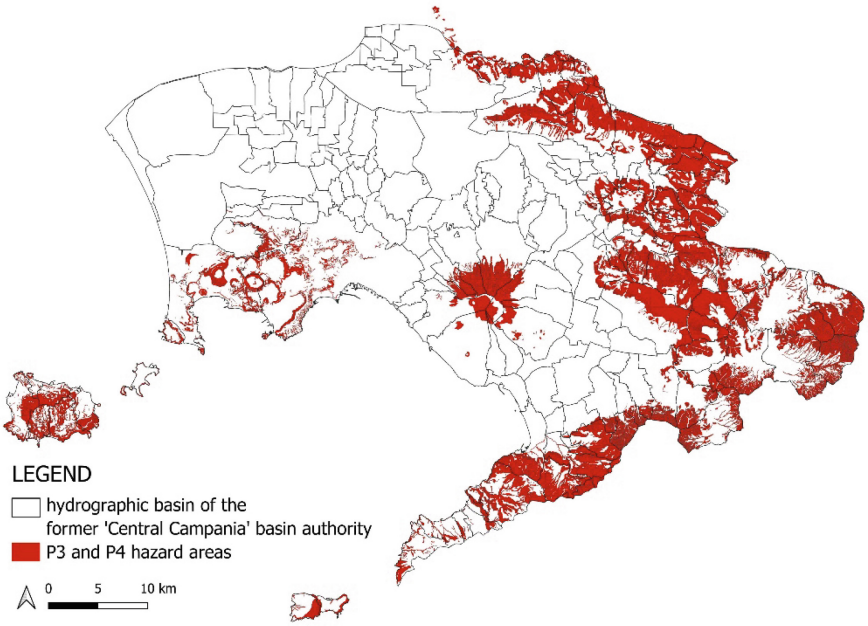


Fig. 3. Identification of high (P3) or very high (P4) landslide hazard areas

To design the networks, the Graphab software was used, using as the resistance values the corresponding scores for soil utilization related to *Ecological Integrity* (IE) and the combination of IE with *Regulating Erosion* (SRec).

Finally, as the last step of macro-phase 3, the overlap map (Fig. 5) of these networks was elaborated, identifying the network which maximizes IE and SRec.

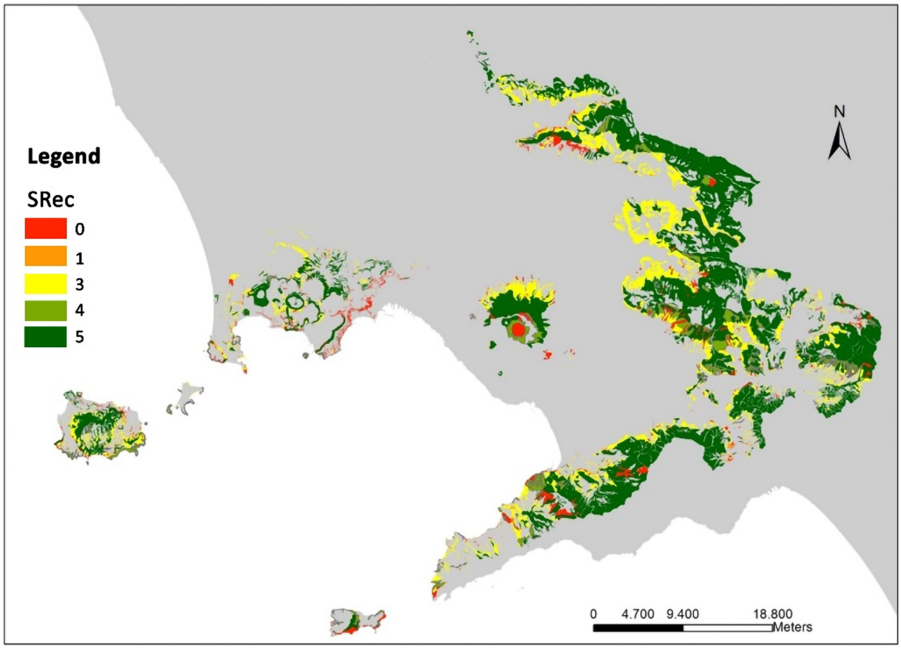


Fig. 4. Intersection of the patches that maximize the SRec and the P3 and P4 areas

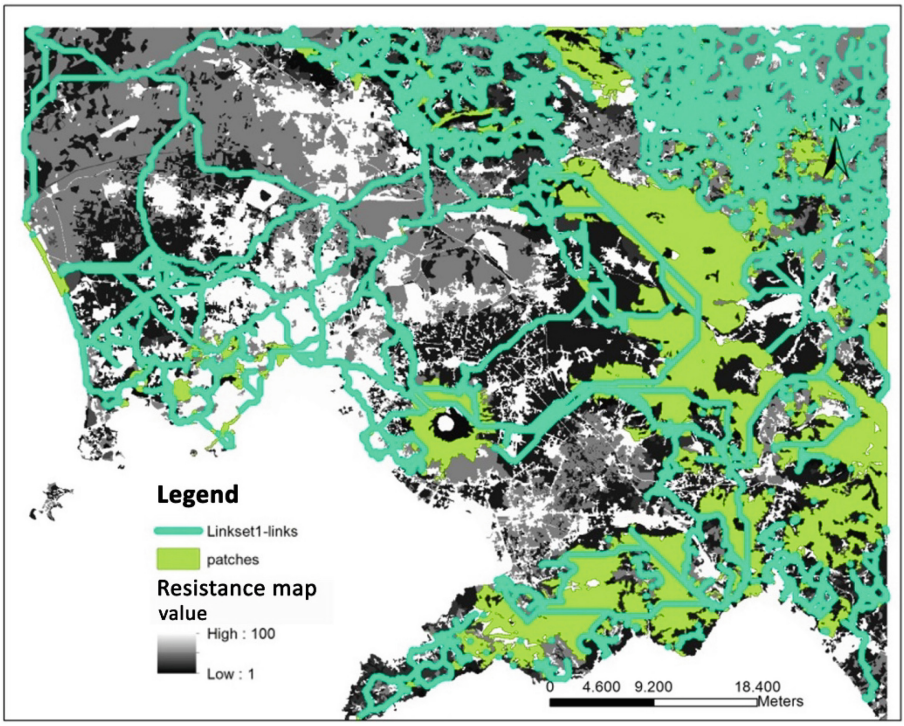


Fig. 5. Overlap map: network that maximises the ESs IE – SRec

6 Discussion and Perspectives

In conclusion, to achieve a territory's resilience, risk assessments must be widely promoted in the development of urban land-use policies.

Integrating the concept of functions and ESs into land management and planning decisions is essential so that local administrators can control the pressures that could threaten the ecosystem.

The potential assessment of soils to establish their ability to provide ESs is considered an important tool to address the current difficulty of systematically considering ESs in spatial planning. However, since ESs have never been quantified in monetary terms, they have always had little or no weight in political decisions.

The proposed methodology addresses the effective planning of GIs network that can help achieve numerous benefits, including the reduction of risks to people and property.

This methodology, therefore, provides a new way of mapping GIs, which is generally based on the specific ability to favour biotic and abiotic flows. In this case, the aim was to optimize this pattern by maintaining and increasing other ESs, starting from the regulation of soil disruption.

The challenge is to ensure that well-planned GIs provide functions that meet numerous planning objectives and become an integral part of public policy; however, this requires thorough planning, design and management.

The case study analyzed shows how fundamental it is for the Campania Region to provide assessment mechanisms in areas with a high risk of landslides and erosion, given the considerable resources allocated to this environmental condition by the PSR 2014–2020.

Most input data were taken from published and reclassified European sources for analysis purposes.

The choices made during the data processing and analysis are based on expert opinions and are open to public control.

On analysis of the overlay map of the SRec distribution and the map of the landslide hazard distribution, the concomitant use of high-value SRec soil with P3 and P4 hazard levels emerges. This information indicates that, on the one hand, the use of the soil performs a protective action, while, on the other hand, that alone does not contribute to the resolution of the problem, mainly due to geological and geotechnical conditions.

From a future perspective, the study should consider identifying strategic priorities [26]. Therefore, using network analysis, based on the theory of graphs, this additional step could provide a comparison between the different networks to define their maximization and mitigation strategies.

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