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PLANNING ADAPTATION. A NOVEL APPROACH TO MEASURE THE VULNERABILITY WHILE FORWARDING TERRITORIAL RESILIENCE

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SUMMARY

The concept of 'resilience' is slippery since its definition depends on the lens of the many disciplines that come together to tackle complex problems with holistic interventions. Acknowledging this complexity means to recognize that i) spatial resilience is influenced by unlinear phenomena (the adaptation and transformation of a co-evolutive system) and ii) spatial resilience is intended as an emergent property of urban planning processes aimed at forwarding the adaptation of the system.

This work wants to present an empirical measure of the vulnerability using the lens of urban planning discipline and therefore solving territorial problems adopting site-specific measures to transform the space. The novelty of the approach is the direct link between the analysis and decision-making process that leads the adaptation planning.

To do so, we employed a Geographic Information System-based vulnerability matrix performed in ESRI ArcGIS 10.6 environment as an output of the spatial interaction between sensitivities, shocks, and linear pressures of the urban system. The vulnerability is the first step of measuring the resilience of the system by a semi-quantitative approach. Vulnerability has been used to define the interventions essential to designing and building the adaptation of the built environment by planning governance. Results demonstrate how mapping resilience aids the spatial planning decision-making processes, indicating where and what interventions are necessary to adapt and transform the system according with the Italian National Plan of Adaptation to Climate Change.

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1. Introduction

If we look at the international scientific debate around the concept of resilience and its relation with urban planning, also considering some practical experiences, the term creates a "conceptual umbrella" that provides a flourishing perspective for urban planning with a slippery and ambiguous definition (Brand and Jax, 2007; White and O'Hare, 2014). The evolutionary definition of resilience provided by Davoudi (2012) is the one that explicitly refers to a co-evolutive condition of a system, and a challenge for planning. Therefore, the dynamic non-equilibrium of a system is an opportunity to create knowledge and intelligence through learning capacity, robustness, adaptation, and transformation (Folke et al., 2010; Holling, 2001).

The implication of this definition in the urban planning agenda is that resilience becomes a normative concept for territorial systems and mainly refers to how a new approach to spatial development supporting the adaptation and transformation of the system could be traced. At the same time, spatial resilience implies that territorial systems continually self-organize and adapt in the face of ongoing and unpredicted changes (Brunetta and Caldarice, 2019). A recent reflection on the theoretical development of a common background on the meaning of spatial resilience in planning has been deepened in the paper written by the Responsible Risk Resilience Centre (R3C) research group of Politecnico di Torino (the manuscript—in press—is entitled "Territorial Resilience: Toward a Proactive Meaning for Spatial Planning"). The work concludes that "territorial resilience" is an emerging concept that supports the decision-making process, identifying vulnerabilities while improving the development of urban transformations coupled with nature-based solutions (Wilkinson et al., 2010).

This paper wants to move a step forward from these theoretical works in the operationalization of this concept, and particularly it works toward the application of a pioneering empirical model to measure the degree of vulnerability in a specific study. The assumption here is that measuring urban resilience is necessary in order to operationalize the concept into a more normative approach for urban planning that shifts from the pure descriptive/analytical assessment to the definition of a spatial support system that aids the definition of the transformation of the system in a long-term and co-evolutive manner.

In this paper, a first attempt into the spatial measurement of vulnerability is presented using a GIS-based framework performed in ESRI ArcGIS 10.6 (Environmental System Research Institute, Redlands, CA, USA) environment as an output of the spatial interaction between sensitivities, shocks, and linear pressures of the urban system. The area of investigation is the Municipality of Moncalieri, Turin (Italy) that represents an optimal context for this study.

The spatial assessment of vulnerability is considered just the first step of measuring resilience of the system by a semi-quantitative approach. The spatial interaction of these measures is useful to define the interventions essential to building the adaptation of the built environment by planning procedures (Allen et al., 2016; Brand and Jax, 2007; Pizzo, 2015).

2. Measuring vulnerability while increasing the resilience

Urban resilience has been measured both quantitatively and qualitatively with a predominance of indicator-based measurements that constitute the most considerable part of the research framework (Allen et al., 2014; Attolico, 2014; Pickett et al., 2004; UNFCCC/LED, 2012).

Measurement is mainly grounded on pre-emptive assessment, with an integration of multi-risk analysis and the qualitative study of governance models (Carpignano et al., 2009; Di Mauro et al., 2006). This specific knowledge is constructed in a GIS environment that creates local datasets to deliver maps of climate and risk vulnerabilities accounting for social, environmental, and economic components of the system (Di Mauro et al., 2006; United Nations, 2015, 2009).

Currently, in a great number of studies, 'vulnerability' overlaps with 'resilience' where the 'resilience' refers to what is properly claimed to be the coping capacity. Such an approach creates confusion and misleading interpretations since the resilience is not an endogenous character of the system (like the coping capacity) and is instead a dynamic and co-evolutive character that depends on the post-disaster effects on socio-ecological and technological systems (SETS) (Markolf et al., 2018). On the other side, what in most resilience frameworks is properly called 'vulnerability', is the sum of a linear or nonlinear relation between sensitivity, exposure, and the coping capacity. Independently of which indicator is, or is not, present in a spatial evaluation of the vulnerable dimension of the system, what emerges is that vulnerability is the product

of a systematic analysis of the state and pressures of the system, while the resilience is a condition that is influenced by the vulnerable dimension but it is not a part of it.

Vulnerability has to be spatially measured including the sensitivity, where sensitivity is the predisposition of the system's components to be affected by potential damages suffering harm as a consequence of endogenous conditions (Béné, 2013; Quinlan et al., 2016; Shin et al., 2018).

In attempting to understand the spatial distribution of vulnerability in a system, a set of indicators were chosen as a proxy of the different group of variables (e.g., environment, land use, economy, and society) (Bollettino et al., 2017). We approached structuring the GIS project to map vulnerabilities, taking into account the numerous limitations of an indicator based on quantitative or semi-qualitative measurements of a resilient system: paucity of data and their comparability, the different time thresholds of datasets, the different spatial resolution and format (vector and raster).

3. Methodology

The spatial assessment of vulnerability is the product of an interaction between sensitivities, disturbances, and shocks mapped by the spatial representation of composite values by raster images with pixel values of 200 square meters (see the list of indicators in the Table 1).

Within this background, our choice was to develop a simple and easy-to-comprehend framework composed of at least three main components that defines vulnerable areas in a pre-defined system. As early mentioned, indicators are grouped into three categories: sensitivity (state of the system), disturbances, and shocks (pressures in the system).

Sensitivities are constituted by the spatial distribution of indicators (index or absolute values) in each part of the territory that are randomly distributed and describe the actual condition of the environment and ecosystem services. The pressures of the system (divided into disturbances and shocks) are constituted by the areas that are affected by external agents of the environment the determined its slow or sudden modification under linear circumstances (land take) or unpredicted events (shocks such as floods or fires).

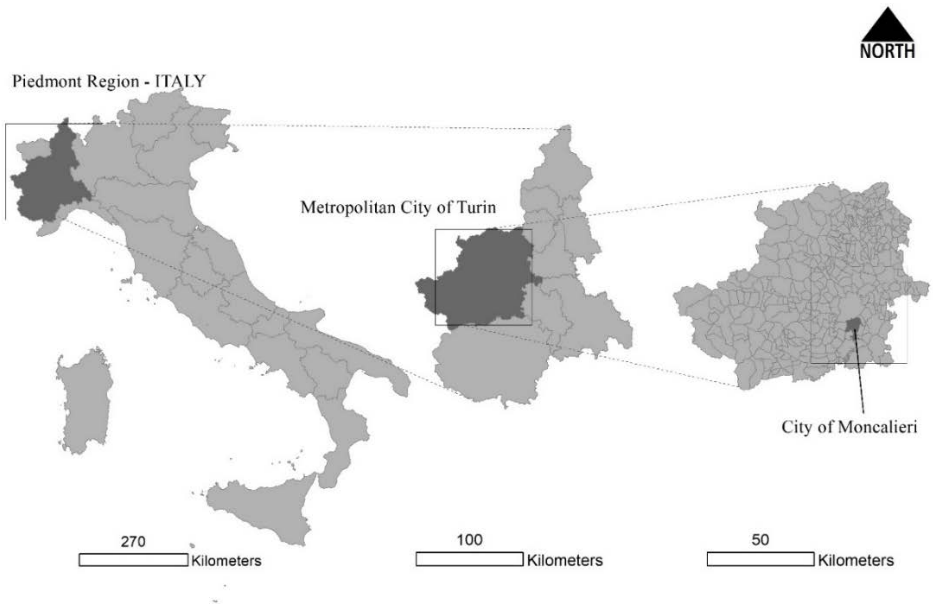
Table 1. List of indicators used for Vulnerability assessment

State of the System					
Sensitivity					
	Indicator	**Structure**	**Source**	**Year**	**Unit**
IMP	Imperviousness	Impermeable surface/pixel	Existent	2012	%
IFI	Ecological Fragmentation	Infrastructure length * weight/pixel	R3C	2016	%
HQ	Habitat Quality	Value habitat/pixel	(InVEST)	2010	%
CS	Carbon Sequestration	Tons C02/pixel	(InVEST)	2010	num
WY	Water Yield	Mm * year/pixel	(InVEST)	2010	num
SH	Landscape Diversity	n.patches * area/pixel	R3C	2010	%
Pressures on the System					
Disturbances					
NDR	Nutrient Contamination	Kg nutrients * pixel/year	(InVEST)	2010	num converted in %
SDR	Erosion	Tons eroded * pixel/year	(InVEST)	2010	num converted in %
CDS	Land Take	Built up areas between 1990 and 2016	R3C	2016	%
Shocks					
IBO	Fires	Buildings near forested areas/pixel	R3C	2010	%
ALU	Flooding	Flooding risk/pixel	R3C	2006	%
ALA	Flows	Run-off/pixel	(InVEST)	2010	%

The presented indicators refers to the component of natural asset (environment and resources) (Sharifi, 2016) that includes ecosystem services monitoring, the quality of landscape, and ecological resources. Here, the most common and diffuse supporting and regulative services are mapped (Maes et al., 2016) (HQ, CS, WY) while a sharp selection of landscape ecology indicators is provided (IMP, IFI, SH). The selection includes the different threats to which these resources are affected by: NDR, SDR, and CDS for linear disturbances and IBO, ALU, and ALA to shocks. The selection of every single indicator follows the recent approach proposed by McPherson (McPhearson et al., 2015, 2014) which indicates the pathway to apply the ecosystem service mapping approach to design resilient cities. The selected indicators resulted in the available work conducted on ecosystem service mapping done by InVEST, and the available GIS vector material shared with the technical office of the municipality. Each indicator has been normalized in values that range from 0 to 1 and distributed in a homogeneous spatial unit of a pixel using the ArcGIS Create Fishnet (Data Management Tool) of the local digital topographic database. Each indicator has been homogenized statistically and stylistically harmonized with the same range of colors form low to a high value.

This methodology has been experimented in the city of Moncalieri. The City of Moncalieri, directly south from Turin, is part of the Metropolitan area of Turin (northwest Italy). The municipality is located in the south-east axis that from the main town follows the Po river course along both the Turin-Piacenza-Brescia and Liguria directions, in line with Alessandria and Genoa. The town has a population of 57,234 inhabitants (ISTAT, 2017) and consists of about 6200 buildings. The city has been chosen for two main reasons: the proximity respect to Turin which has influenced the development of this district of the metropolitan area that is not an isolated and autonomous system but a dense conurbation of approximately 60 thousand inhabitants, and the topography of the city, which is composed by a heterogeneous hilly topography with particular flat part subject to flooding. Moncalieri has a quite inhomogeneous orography and consists of a flat part that develops mainly in the southern and western sectors of the municipal boundaries, and of the Po river basin that from the City of Moncalieri enters in Turin along the Turin hill ridge (Borgogno-Mondino et al., 2015). The settlement system has developed transversely to the north–south axis of the river, approaching to the hill that contradistinguish the city of Turin. However, Moncalieri has also extensively expanded in the sloping northern part of the municipal territory, where settlements mainly distribute along the main streets that provide access to the Turin hill, also with high-density land uses (Cassatella, 2013).

Figure 1. Location of the context of study



3.1 Sensitivity

As introduced earlier, sensitivities are made up of indicators that range from the landscape ecology to ecosystem services. Notably, in this work, six different indicators were selected:

- three indicators refer to the landscape ecology approach on environmental planning (IMP, IFI, and SH);

- three indicators refer to ecosystem services dimension (HQ, CS, WY);

Sensitivity here is calculated as the predisposition of environment and ecosystem services to be sensible to events due to intrinsic conditions that lead the inclination to suffer if the available resource will be destroyed. Therefore, values increase where the environment presents a good quality (thus it can be damaged by disturbances and shocks) and its ecosystemic functions are well-provisioned, too.

IMP—Impermeabilization, that is the permanent sealing of topsoil due by asphalt, concrete, and other non-permeable construction materials, is the most diffuse and degrading effect of the urbanization process (Artmann, 2014; European Commission, 2012). The impermeable surface of an urban area does not correspond to its entire dimension since urban areas are not completely sealed, therefore some urban systems are more sustainable of others since the permeability of urban areas can be considered a good proxy for the environmental condition of a built-up system. For this indicator, it has been employed the national sealing map available at www.consumosuolo.isprambiente.it that is the result of Copernicus High-Resolution Layer-Imperviousness Degree (2012) data. The indicator distributes in a pixel area of 5 m the information of land cover, where pixels with 1 value indicates a sealed area, while pixels with 0 value indicates an unsealed area.

IFI—Ecological fragmentation is an important indicator of the healthy condition of the ecological system since the isolation and the creation of patches into the ecological mosaic is one of the prominent threats for the ecological processes that regulate the environment (Bennett and Mulongoy, 2006). IFI has been conceived, assuming that there is a spatial well-detailed knowledge of the network system that cuts the landscape continuity interrupting or degrading the potential connectivity. The fragmentation caused by the road network can be weighted according to the magnitude of the road system, generating a spatial index that displays the effective fragmentation of the ecomosaic.

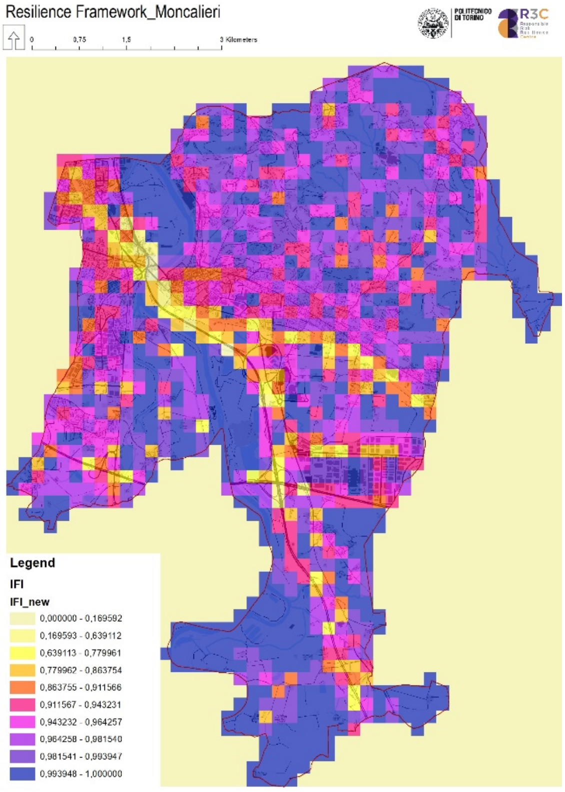
SH—The landscape diversity index reflects how many different kinds of land uses there are in a minimum detected unit (pixel of 220 sqm), providing a distribution of the different components of the landscape where higher values reflect a richer heterogeneity of landscape patches in the observed unit (Benini et al., 2010; Mosammam et al., 2016). This indicator is heavily used in landscape ecology to assess the species diversity or the ecological diversity in a specific area of investigation. It reflects how the landscape is composed of different patches that correspond to the land use polygons. The assumption here is that a mixed composition of the land uses that includes also anthropic areas helps to increase the quality of the landscape in general.

HQ—The map of habitat quality has been employed as a proxy of biodiversity since high quality of habitats supports the development of all ecological functions (Nelson et al., 2011). The supporting ES of habitat quality has been produced using InVEST software. Habitat quality combines information on LULC and threats to generate maps that includes the degradations due to sources of habitat disturbances.

CS—The carbon sequestration is an ES related to the capacity of the soil of storing in the biomass and dead mass above and below ground to store CO_2. Ones that soil is sealed it lost its capacity to store the atmospheric carbon and therefore the storing capacity of soil influences the quantity of carbon that is present in the atmosphere. This ES has been mapped to model carbon storage and sequestration of InVEST that maps carbon storage densities to a different kind of LULC.

WY—The water yield is an ES that refers to the water storing capacity depending on the structure and the physical structure of the ground and the aboveground vegetation. Changes of land use profoundly affect hydrological cycles affecting the evapotranspiration that is a primary function that modifies the water availability and microclimate conditions.

Figure 2. An example of sensitivity: IFI



3.2 Disturbances

Disturbances are linear and predictable trends that affects the system gradually altering its condition. Therefore, are areas of the system that are affected by slow modification due to particular processes that affect sensitivities. As to what concerns the component of Environment and Ecosystem Services, the selected disturbances are composed by three indicators:

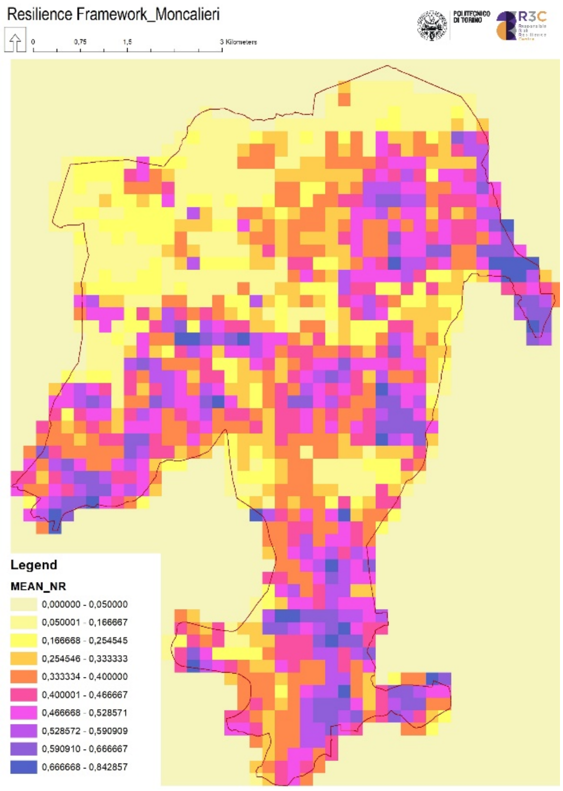
- Two indicators depend on soil ES: nutrient contamination—NDR that is an output of the model nutrient retention of InVEST; and the Erosion—SDR, that is an output of the model sediment retention of InVEST;
- One indicator refers to the landscape transformation due by the process of urbanization: the land take indicator—CDS represents the areas where the process of urbanization has been concentrated in the last years.

NDR—the nutrient retention model of InVEST calculates the areas where diffuse pollutants flow into streams. The model routes the nutrients path along the environment. Mapping nutrient retention make clear the effects of anthropic activities on water quality (Salata et al., 2017).

SDR—Sediment retention model works towards the interaction of the digital elevation model and the soil characteristics computing the amount of the annual soil loss in each pixel, therefore calculating the soil loss that reaches the stream. This ES is pivotal since its account for one of the most dangerous and pervasive kinds of degradations that affect soils at different scales.

CDS—The land take indicator indicates the amount of new impermeable surfaces due to new urban areas (Gardi et al., 2015; Salvati et al., 2012). This phenomenon is associated to the loss of the non-renewable resource of soil that is caused by the substitution of agricultural and natural/seminatural land to artificial land.

Figure 3. An example of disturbance: CDS



3.3 Shocks

Shocks are unpredictable and dangerous events that threaten the system occasionally and with high impact for the environment, settlements, and populations. Shocks are intended as the major catastrophic events that the system has to absorb in case of adverse conditions. Shocks are unpredictable since their occurrence is viewed in a long-time period and, moreover, their effect is unpredictable too.

Shocks are composed by three indicators:

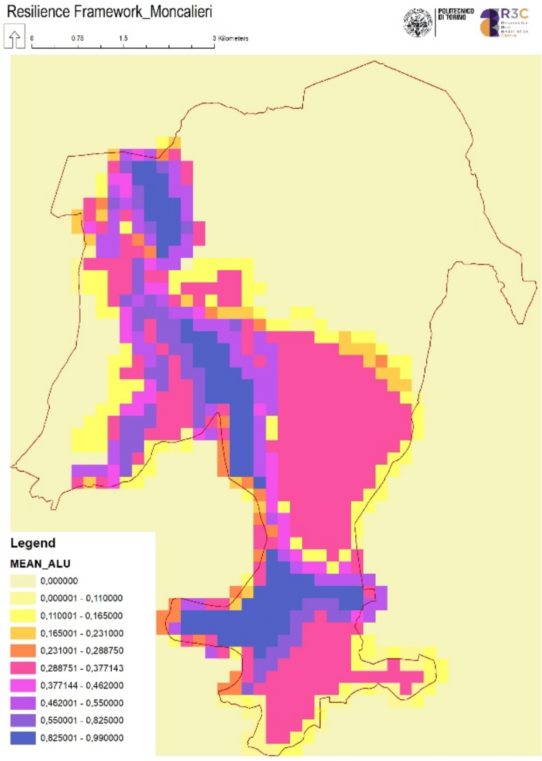
- An indicator refers to the risk of fire IBO;
- Two indicators ALU and ALA refer to meteo-hydrological related risks. ALU represent the spatial distribution of flooded areas in case of a catastrophic event while ALA represents the areas that are threatened by high run-off processes and therefore are affected by debris flows.

IBO—The spatial distribution of fires risk has been obtained by an autonomous elaboration that has been conducted using the methodological requirements of the Italian Civil Protection that is the selection of areas where buildings are less than 10 m from a forested area. This condition is evaluated as potentially dangerous in case of fire since these buildings are highly exposed to flames.

ALU—This indicator has been calculated using the ancillary map of the flooded areas of the event that occurred in 2016 that has been considered 'catastrophic' since the flooding overcomes for large parts the maximum exposed areas that the hydrological plan was originally considering. This event showed that the traditional single risk maps underestimate the potential effect of a natural hazard where the accumulation of causes generates a highly dangerous condition.

ALA—This indicator differs from the previous since the phenomena of intense rainfall can generate in the medium period a flood peak in the existent streams, but at the same time in the short period, the run-off along sloping areas often causes debris flows where the soil reaches the point of saturation. This is the case of hilly areas, but also the plain areas in low drainage soils that reach the saturation in case of heavy rain. This indicator has been created using the InVEST Nutrient Retention model that generates a preliminary intermediate output where each pixel of the landscape is affected by a run-off index.

Figure 4. An example of shock: ALU



4. Results: mapping vulnerability

Once the sensitivities, disturbances, and shocks were mapped with the same parcel units the spatial overlay of each component has been employed to generate a final index of the overall evaluation of variables, where the vulnerability here is intended as the unweighted sum of sensitivities with the disturbances and shocks.

The map is the product of the per-pixel formula that follows

$$Vul = Sen + D + S$$

where

Vul = vulnerability of the system

Sen = sensitivity composed by a composite unweighted sum of IMP + IFI + HQ + CS + WY + SH

D = disturbances composed by a composite unweighted sum of NDR + SDR + CDS

S = shocks composed by a composite unweighted sum of IBO + ALU + ALA

The dark violet areas are the ones where the highly sensible pixels interact (are exposed to) linear pressures and unpredictable shocks. Therefore, it is highly probable that from an environmental and ecosystem perspective, the system is subjected to disruptive effects in that parts, both in case of unpredictable natural hazards or long-time exposures to linear pressures that modify the state of the system. This represents the first step into the experimental spatial measurement of the resilience of the system whereas the system is considered more resilient when is less vulnerable in a first attempt. In this view, resilience is the product of a combined reduction of vulnerability with and augment of adapting and coping capacity.

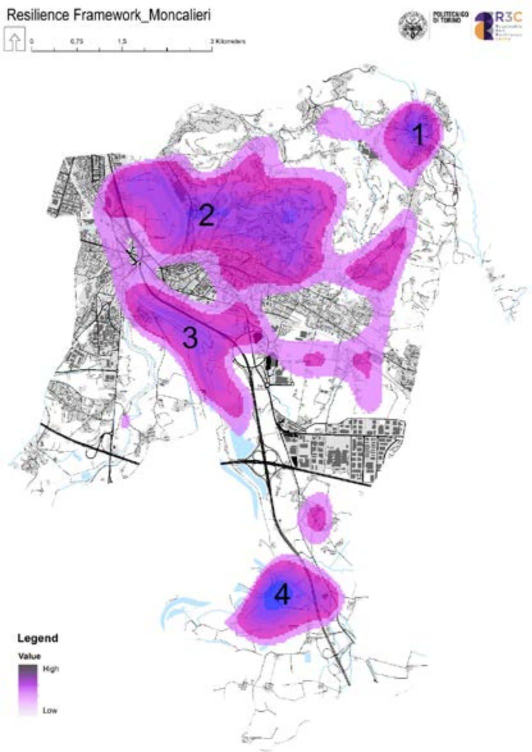
The distribution of dark violet areas is mainly concentrated in four priority areas:

The hilly development of Revigliasco (area 1) which comprises the landscape of natural and seminatural forested areas with the disperse and fragmented settlement system that is developed along the historical track, namely “Strada della Maddalena”. Here, a high vulnerability is particularly due to the probability that an event (fire) occurs destroying the rural and natural environment characterized by the presence of human settlements that are composed by detached and semi-detached houses with a high landscape and scenic quality.

The upper town development (area 2) along the panoramic routes that provides accessibility to the hilly semi-detached development that forms a continuum with the dense and highly developed ancient town center. This part of the system is characterized by high promiscuity between the natural landscape and the built-up system made up by villas and big private gardens and parks. In these areas, the development of the real-estate market for upper-class development of the city has been historically polarized and the vulnerability is characterized by the predominance of the land take disturbance over these areas;

The rural Po riverbed (areas 3 and 4) that is constrained between the A6 Highway Torino-Savona, the national ancient street that connects Torino (Nichelino) and Carignano, the railway, and the national road to Carmagnola. This part of the landscape preserves the character of a humid ecosystem only along the stripped riverbanks because it has historically subjected to a high process of urbanization and hydraulic regulation. The landscape comprises intensive seminative fields with dispersed settlements on the west side with orchards and some formerly productive sites. Here, the vulnerability is mainly due to shocks (flooding) that compromises the environmental and ecosystem integrity of the system and to highly sensitive parts of these areas that are sensitive to hydrological regimes.

Figure 5. Vulnerable areas



The utilization of the map is crucial to define the kind (what) of interventions in urban areas that are necessary to lower the vulnerability of the system. Intervention ranges from the most commonly used ‘green’ nature-based solutions (Raymond et al., 2017) to infrastructural ‘grey’ interventions. The bullet point that follows results from a first recognition of interventions categories that spans across a multitude of potential possible measures.

To what concern Moncalieri, some actions should be developed in vulnerable areas. In areas 3 and 4, preferable actions range from different measures to achieve flow regulation:

- planting green roofs or green walls to intercept rainfall;
- creating rain gardens/plaza reducing run-off;
- create underground water storage that increase the absorption capacity of urban areas;
- urban catchment forestry to retrofit sustainable urban tree cover to reduce flood risk;
- floodable parks to absorb flood peaks.

While the hill (areas 1 and 2) should pursue a de-sealing process with a rational regulation of the interconnection between natural areas and the built-up system.

- creating landscape connections with urban green space—trees, alleys, hedges, riparian vegetation;
- increase biodiversity within green areas, paying particular attention to the distance between forested areas and settlements to cope with fire risk;
- urban catchment forestry to retrofit sustainable urban tree cover to improve water supply;
- natural wastewater treatment to reduce drinking water consumption for irrigation.

These measures are just some of the solutions provided by the national guidelines to define the Adaptation to Climate Change—according to the Italian National Plan of Adaptation to Climate Change (PNCC, 2016)—that we purpose here as an operational methodology that links the assessment of vulnerability to the definition of a selected target of transformative measures.

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