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A METHODOLOGICAL PERSPECTIVE TO ASSESS SPATIAL RESILIENCE

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ABSTRACT

The debate around resilience is focusing on different "dimensions" that represent its co-evolutionary and multidisciplinary innovative aspects. Nowadays, the scientific and academic debate is mainly working at the theoretical stage while at its practical level the measurement of "resilience" remains undefined or based upon traditional models. Nonetheless, even if at the linguistic level the academy aims to distinguish resilience from sustainability, at the practical/methodological level the index and indicators used to assess the resilience are often confused and overlaps with the ones of the sustainability.

In this paper, an empirical test is conducted in the area of the Metropolitan City of Turin. A GIS-based Ecosystem Service map has been used as a proxy to demonstrate how the indicator of Water Yield provision can be used in the view of sustainability rather than in the view of resilience.

A statistical and geographical comparison of the indicators demonstrates that resilience differs from sustainability and require an in-depth assessment that didn't overlap with the sustainability assessment.

This first result provides innovation for urban planning since it demonstrates that resilience has a proper character not only at the epistemological level but also at its empirical and practical stage.

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1. Introduction[3]

The existing scientific literature and some practical experiences seem to investigate resilience using the "multidisciplinary paradigm" which includes approaches and concepts of ambiguous definitions (White and O'Hare, 2014). At the same time, the debate around resilience attracts many interpretations that produced new analytical, interpretative and representation models of territorial dynamics to generate innovations on spatial planning policies which address global changes by i) the co-evolutive perspective of territorial systems (Folke, 2006) and ii) the holistic approach to planning which states that resilience is a process rather than a product of the system (Davoudi *et al.*, 2012). The resilience is the capacity of an urban system to maintain or restore its basic functions after internal or external stress, adapting and transforming itself into a new dynamic. By this perspective, the relevant characters of a resilient system are learning capacity, robustness, innovation capacity, adaptation capacity, thus to overcome the "single-state equilibrium" to forward a "dynamic non-equilibrium" where uncertainties are assumed as innovating factors (Angeler and Allen, 2016). Therefore, for what concerns the assessment of resilience, the traditional quantitative/qualitative models are inadequate to meet an evolutionary state which requires ad-hoc adaptability to the system.

Rather than a traditional deductive model, it seems to be much more interesting and fascinating to develop an ad-hoc assessment based on site-specific requirements. If resilience is a process, its measurement should be fluid and dynamic rather than fixed and unique. This change in perspective stimulates the debate around the issue of how a scientific approach to resilience requires an abandonment of pre-determined methodologies and opens to an evolutionary and changeable/adaptable approach.

These visions pose two crucial conditions for territorial planning: the conservation of a memory of the system and the evolutionary capacity to measure resilience with fluid approaches that consider different measures: preparedness (learning capacity), persistence (being robust), adaptability (being flexible) and transformability (being innovative), in a co-evolutionary perspective.

Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain (or rapidly return) to desired functions in the face of a disturbance, to adapt to change, and to transform systems that limit current of future adaptive capacity quickly (Meerow, Joshua P. Newell and Stults, 2016).

Fostering a resilient approach in the face of environmental and socioeconomic uncertainty and risk is an important goal for cities because urban areas hold the majority of the population in the planet and thus they are a laboratory for resilience. Nevertheless, the definition of resilience is still ambiguous and, moreover, the operationalization of resilient approaches is not a common procedure in urban planning practices. Actually, resilience is just a pioneer approach for territorial policies and gains popularity both in the academic and policy discourse as well, even if the term has been so long discussed into the disciplinary debate around socio-economic systems (Adger, 2000). The limit of resilience is its practical implementation since no common approaches are shared and practiced.

From ecological resilience to engineering resilience (Holling, 1996) the updated interpretation of urban resilience seems to goes beyond the concepts of "stability" or "equilibrium" dealing with an uncertain view in the face of changing socio-ecological conditions. The concept is evolved into a more holistic view that is the socio-ecological perspective of understanding systems as in a non-linear changing dynamic, dealing with future uncertainties. The literature review around the concept of resilience shows that the definition does not address a fixed point and conceptual interpretations spans from a broad concept around the concept of

[3] This work is an outcome of the collaboration between the Interdepartmental Responsible Risk Resilience Centre (R3C) of DIST, Politecnico di Torino, with the PhD candidates Fabio Jose Benez Secanho and his supervisor Prof. Puneet Dwivedi from the Warnell School of Forestry and Natural Resources, University of Georgia (US)

vulnerability, to a more focused definition that refers to adaptability to face internal and external disturbances.

Enhancing resilience in urban systems means to demonstrate a measurable reduction of the vulnerability of urban areas towards climate change and other natural hazards and, on the other side, through the improvement of Nature-Based solutions by new knowledge and tools employed by the local communities. This paper has the following structure: paragraph two offers a discussion about the existent contraposition between sustainability assessment and resilience assessment which is much more methodological rather than ontological. Then, in section three, it will be presented a gis-based empirical evaluation of an Ecosystem Service (ES) indicator analysed by the lens of sustainability and the lens of resilience. In the discussion and conclusions (paragraph four) it will be demonstrated that the traditional ES GIS-based analysis presents substantial differences when used to measure the resilience of a system.

1. 1. The three preconditions of Resilience

The appropriateness of a specific method to measure the resilience depends on the adaptation or risk management issue to be addressed, including, for instance, the time and geographic scale involved, the number and type of actors and economic and governance aspects. Indicators, indices, and probabilistic metrics are important measures and techniques for vulnerability and risk analysis. However, quantitative approaches for assessing vulnerability need to be complemented with qualitative approaches to capture the full complexity and the various tangible and intangible aspects of vulnerability in its different dimensions.

Attention to the temporal and spatial dynamics of vulnerability and exposures is particularly important given that the design and implementation of adaptation and risk management strategies and policies can reduce risk in the short term, but may increase vulnerability and exposures in the long term.

A resilient approach to cities and territories requires an accurate evaluation of risks, taking into account some preliminary definitions:

- the risk is multi-dimensional and differential. It varies across physical space and change over time;
- exposure is not vulnerability. You can be exposed but not vulnerable while you cannot be vulnerable without being exposed. If exposure remains an external (constant) value, then mitigation measures will be aimed to lower the vulnerability and, at the same time, to augment the resiliency;
- sensitivity is the physical predisposition of human beings, infrastructure, and environment to be affected by a dangerous phenomenon due to lack of resistance and predisposition of society and ecosystems to suffer harm;
- vulnerability is the propensity of exposed elements to suffer of adverse effects when impacted by hazard events. Is the lack of resilience or capacities of the exposed system to cope and adapt to events. Vulnerability includes an environmental dimension that deals with the role of regulating (and others) ESs which direct impact human well-being (Millennium Ecosystem Assessment, 2005);

Resilience also deals with education: a well-informed and motivated population can lead to disaster risk reduction but it requires the collection and dissemination of knowledge and information on hazards, vulnerabilities and capacities;

Assuming the above-mentioned paradigms this paper tries to argue that a measurement of the resilience is necessary for its practical implementation in urban planning since its measurability in the space and time proves its “existence” in an empirical way. This means that this paper oversimplifies some “epistemological” concepts working at the “methodological” level and putting in evidence the conditions where the measurement of resilience could be addressed. There is a need for an assessment technique that considers

resilience in different context assuming some requirements such as multi-scalarity, multi-dimensionality, objectivity and subjectivity, genericity, independently (Béné, 2013).

In this text, the decision-making application of resilience is far from being evaluated as this adds complexities which are far beyond this methodological/empirical demonstration which is based upon some conceptual preconditions. In our view, the measurement of resilience is based upon three main paradigms.

First: the time. Measuring resilience means to face temporal thresholds and look how phenomena changes in time responding to something (external or internal stress) and not to describe static events. This condition excludes all the approaches that did not observe a trend and focuses on single “static” indicators. As introduced, resilience is a “condition” that can be reached in different ways with planned and unplanned or spontaneous measures. A socio-ecological system which can be described in “fair” condition by a static indicator can be incredibly resilient by its intrinsic character (of the population for example) and to react at external stress faster than other systems (Pizzo, 2015; Meerow, Joshua P Newell and Stults, 2016).

Second: the quality of phenomena. Measuring resilience means to adopt a multidisciplinary methodology of measurement that includes numeric and non-numeric variables. This covers aspects of society and economy that are not typically “measurable” by quantitative analysis. Some studies argue that the assessment process and indicators of resilience are qualitative thus eliminating a large amount of quantitative data collection (Woolf *et al.*, 2016). This assumption implies that it is important the assessment is “holistic” and “inclusive” rather than truly “weighted” to achieve practical operability by local administrators.

Third: resilience isn’t sustainability. This particular condition is what the paper tries to demonstrate presenting an in-depth argumentation.

2. Sustainability vs Resilience

The traditional analysis of the socio-ecological system is still rooted in the concept of sustainability rather than the ones of resilience. Sustainability refers to the capacity of meet the needs of the present without compromising the resources of the future generations (UNICEF-ONU-UNESCO, 1987).

This leads to adopting wrong assessments and creates confusion in the research system. Even if sustainability is strongly connected with close life-cycle systems and it appears to be a concept that encapsulates a resilient condition, the way resilience should be assessed and measured has just a few in common with the measurement of sustainability. As regards the abovementioned three preconditions it could be argued that a sustainable system has been commonly measured using just quantitative “stock” parameters without considering how the system “react” to an internal/external stress. This, in the view of adopting resilient solutions, implying that a different framework for measuring resilience is far from being developed by the scientific community and this work goes in the direction suggested by other authors that reviewed the methodologies to assess resilience to built-up a common framework (Sharifi, 2016).

The tools and indicators that comes from the traditional landscape ecology school, nor the ones largely diffused by the Strategic Environmental Assessment introduced by Directive 2001/42/EC of the effects of certain plans and programmes on the environment (SEA Directive) and even the DPSIR (Drivers, Pressures, States, Impacts, responses) framework which analyse the interlinked relationship between social and environmental factors are all focused on the paradigm of sustainability. Agenda 21 (United Nations, 1992), the Millennium Development Goal (United Nations, 2000), the European Sustainable Development Strategy (European Commission, 2001) and the EU Flagship policies 2020 (European Commission, 2010) are, among others, relevant policies to prompt sustainability and not resilience.

Sustainability of local, regional and national plans and programs has been the major target of the territorial policies in the last couple of years since plans and programs worked to pre-determine an ex-ante vision of the system it has been agreed that the required natural, social and economic capital has to be maintained over the time (Holden, Linnerud and Banister, 2014).

This massive utilisation of the paradigm of sustainability, especially during the procedures of evaluations of plans and projects, has deprived the possibility to measure its character using a holistic and scientific ground approach which should include a broader conceptual approach. Some studies argued that few assessments in the last years correctly approached at sustainability and most of them were reduced to a poor "threshold approach". While in a systemic review of the sustainability assessment it is clearly demonstrated that the characteristics of sustainability assessment call for 1) adopting a holistic approach, 2) using transdisciplinary, 3) integrating different methodologies, 4) collaborating and participating, 5) linking local/social context, 6) having a normative function, 7) promoting social learning and 8) dealing with uncertainties. Unfortunately, although recognised, these characteristics are not found in the practical/empirical examples (Sala, Ciuffo and Nijkamp, 2015).

Therefore, the measure of resilience shouldn't be formalised in any legal action until its definition/evaluation is clearly defined; otherwise the risk is to confuse procedures to assess sustainability with a broad framework to determine resilience.

Secondly, an essential character of the abovementioned framework considers necessary to put in practice the monitoring phase, which is crucial to delivering a real awareness of the right direction of a specific policy to the system. The possibility to correct, adjust and inform an administration on the ongoing implementation of a plan should be not confined to the decision-making phase, but also extended during the execution of a program. Such a "continuity" is contraposed to the threshold approach which tends to minimise each indicator which is below the critical value. Finally, there is an epistemic uncertainty addressing resilience which assumes that a full understanding of the effects on socio-economic systems of a new internal or external stress is beyond our capacities while sustainability tries to do it.

Therefore, leaving apart the different interpretations, a framework to measure resilience has to be composed by an operational system that adopts new targets that fixes up the results of the various assessment.

2. 1. Sustainability, Resilience and urban Ecosystem Services

As it has been accurately described by McPhearson et al. (2015) many cities adopted sustainability plans while few addressed a resilient approach. Moreover, in the large majority of cases, often sustainability and resilience are used interchangeability (Redman, 2014).

Table 1- Contrasting elements of resilience and sustainability.

Resilience Theory Approach	*Sustainability Science Approach*
Change is normal, multiple stable states	Envision the future, act to make it happen
Experience adaptive cycle gracefully	Utilize transition management approach
Origin in ecology, maintain ecosystem services	Origin in social sciences, society is flawed
Result of change is open ended, emergent	Desired results of change are specified in advance
Concerned with maintaining system dynamics	Focus is on interventions that lead to sustainability
Stakeholder input focused on desirable dynamics	Stakeholder input focused on desirable outcomes

Source: Redman, C. L. 2014.

Despite this, the reduction of disaster risk and of the vulnerabilities to climate changes require a specific approach to urban resilience defined by a common theoretical assessment that is capable of steering the future practices.

In the above-mentioned paper it is argued that ESs and resilience are related in two ways: first incorporating ES in urban planning and second safeguarding a resilient supply of ES in the long term. As regard as the latter point, in this study, it is proposed a comparison between two different ways to incorporate

ES assessment in urban planning, in the first case using a basilar threshold approach assuming a typical sustainability analysis of ES, while in the other using a scenario planning approach to perform a resilient analysis of ES (Sala, Ciuffo and Nijkamp, 2015).

Such approach wants to empirically demonstrate that GIS-based ES mapping provides information that can be used to address measurement of the sustainability rather than of the resilience and that the two are highly different.

It is here underlined that a resilient approach presents a slightly different perspective in the utilisation of ES for decision-making evaluation in planning since the large majority of methodologies comes from the environmental school which is still rooted on the threshold definition. According to the traditional framework of sustainability, a socio-ecologic system that provides enough ES at a certain scale and for a certain amount of population demand is defined sustainable when the "anthropic" demand for the service is satisfied by the available resources. All the theories on ES mapping and assessment follow this approach: the supply-demand satisfaction is considered essential for the evaluation of sustainability (Burkhard *et al.*, 2012) thus the definition of the threshold is the main issue. However, is this threshold valid under rapidly changing conditions? In addiction, is the ES assessment in the view of sustainability equal to the ones of resilience?

Hereafter, it is demonstrated that ES assessment in the view of resilience has to address the question of how the provision of ES is affected by variability (in this case by a possible climate change condition) rather than to understand if the supply of the ES satisfies the anthropic needs. For this experiment, the scenario approach is simplified simulating that in the future a reduction of rainfall will affect the water yield capacity of a system. This criterion excludes that the interchanges of internal drivers that will affect ES capacity, but also this consideration in the future could help urban planning to become more adaptive.

3. An empirical experiment

For what concerns the assessment of resilience, the traditional quantitative/qualitative models are inadequate to meet an evolutionary state which requires ad-hoc adaptability to the system.

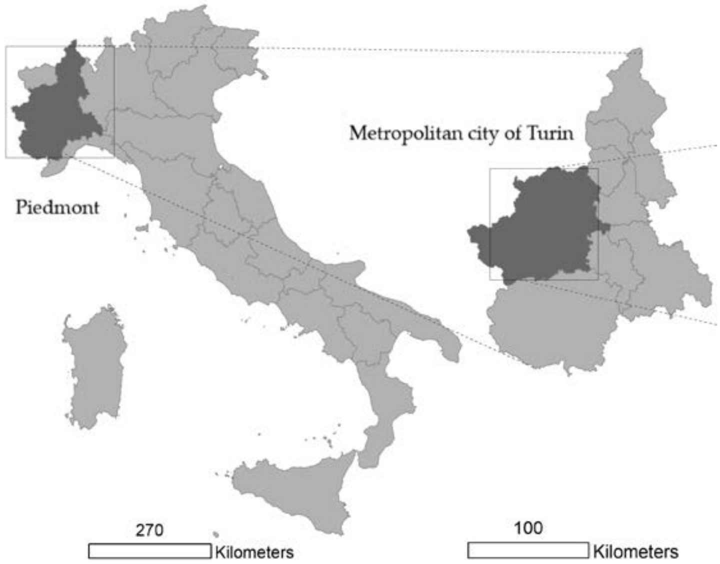
Rather than a traditional deductive model, it seems to be much more interesting and fascinating to develop an ad-hoc assessment base on site-specific requirements. If resilience is a process, its measurement should be fluid and dynamic rather than fixed and unique. This change in perspective stimulates the debate around the issue of how a scientific approach to resilience requires an abandonment of pre-determined methodologies and opens to an evolutionary and changeable/adaptable approach.

To address these questions, an empirical experiment has been conducted to test how the output of a sustainable indicator can be compared to a resilient indicator. To do that, one of the most important ES (Water Yield) has been selected to model the water provisioning in a context of study. Ones that the ES model generates the quantity of retained water a GIS-based analysis has been applied to see:

- if the quantity of the water yielded in the territory is sufficient to satisfy the local demand (sustainability indicator)
- how the Water Yield capacity reacts to climate change (resilient indicator).

This study selected as target one of the most relevant areas of the Po River (Turin, Italy) watersheds: the metropolitan city of Turin.

Figure 1 – The study area (source: author's elaboration)



The area spans 6,827 Km^2 with 2,269,902 inhabitants. The Metropolitan area is composed of 316 municipalities. The selected territory has different socio-morphological characterisation: the context of first-ring cities is highly urbanised and infrastructured while there are second-ring municipalities located in the hilly and rural part of the urban context that is contradistinguished by a high scenic landscape and a suitable natural environment. The plain part of the territory is composed by the flat and low valley which belongs to the rural-metropolitan character.

Spatial and tabular data were collected and the InVEST (Integrated Evaluation of Ecosystem Services and Tradeoffs) Water Yield model has been used to calculate the retention in the catchment area. Outputs have been analysed through its biophysical values and, subsequently, by their sustainability and resiliency attributes.

As anticipated, the software used for calculating the potential soil loss is InVEST which is one the leading open access product of the Natural Capital Project. The InVEST Reservoir Hydropower model estimates the relative contributions of water from different parts of a landscape, offering insight into how changes in land use patterns affect annual surface water yield in a specific territory (Nelson *et al.*, 2011).

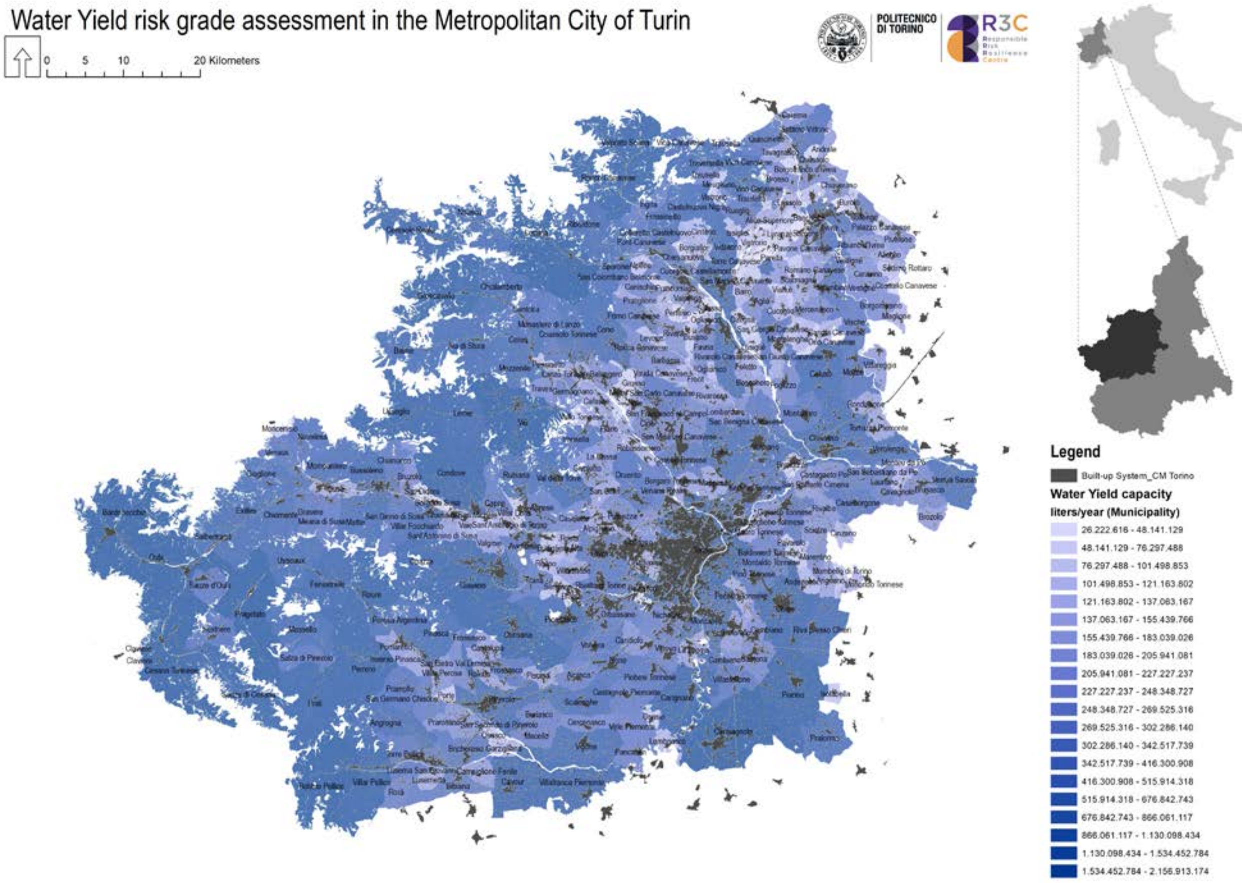
InVEST is currently adopted as main ES mapping software by different kind of users and a network of the analysts. The main advantage of the software is its simple availability and its direct usability.

The baseline analysis has been carried using the Regional Land Cover raster dataset of 2010 (Land Cover Piemonte – LCP) with a resolution of 1:10.000. This dataset is of high utility and precision (more than 30 land use classes represented with a 20 meter cell resolution).

Other data needed are root-restricting layer depth, precipitation, plant available water content, average annual reference evapotranspiration, watersheds and the biophysical table (a table of land use/land cover classes, containing data on biophysical coefficients used in this tool).

The result of the model is represented in the fig.1 where all the municipalities of the Metropolitan City are ranked according to their capacity of yielding the water.

Figure 2 – The Water Yield model (source: author's elaboration)



The minimum value in the 316 municipalities is 745,217,427.1 (Litres per year) while the maximum registered is 85,815,330,124.5 (mean 11,487,137,654.4 and standard deviation: 14,057,828,017.8.

3. 1. An ES indicator of sustainability

Given the total amount of provision of water for each municipality, it has been decided to see which is the degree of sustainability of the system looking at how the amount of water yielded in the territory satisfies the yearly demand of water for different uses (civic and agricultural). To assess the demand of water, it has been used the Turin average civil consumption per inhabitant (ISTAT census 2011 – 77 m3 per inhabitant/year equal to 77.000 litres/inhabitant/year) available at http://dati.istat.it/Index.aspx?DataSetCode=DCCV_INDACQDOM

Ones calculated the quantity of inhabitant for each municipality it has been created a spatial representation of the civic demand using an ESRI ArcGIS 10.6 "join" function.

Subsequently, it has been assessed the average consumption for agricultural which has been provided by the technical annexe of Piedmont Region.

Table 2- Demand of water for agricultural uses

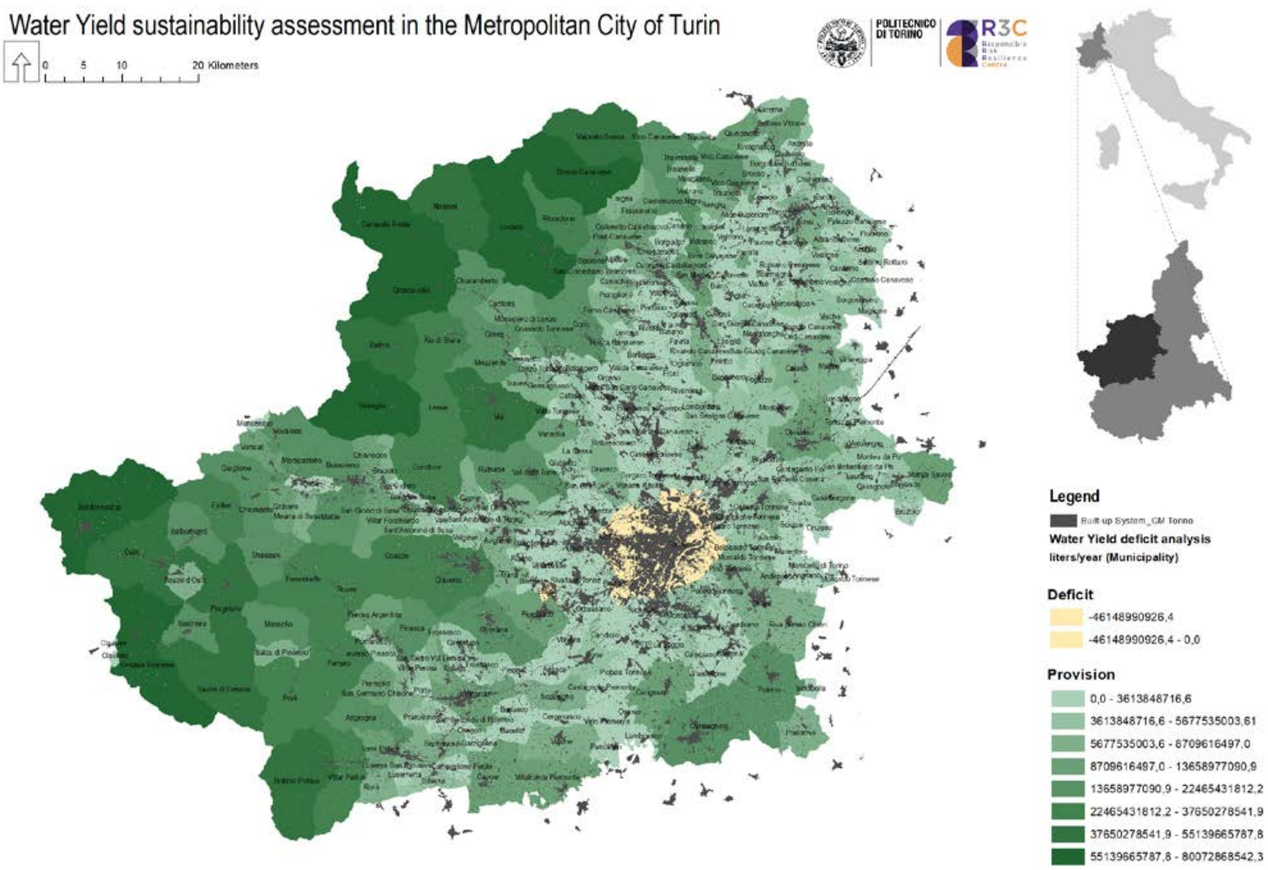
Kind of culture	*Average water consumption (mm/year)*
Rice	2,200
Corn	310
Forages	360
Fruits	370
Grasslands	360
Beet	75

Orchards	400
Soy	100
Potato	470
Others	250

Source: technical annex of Piedmont Region (1 July 2004 with data prediction for the period 2008 – 2016)

The provision, less the fraction of the consumption of water turned out to represent the sustainable assessment of the ES Water Yield.

Figure 3 – The Water Yield sustainability (source: author's elaboration)



As it can be viewed in the figure, despite the city of Turin, all the other municipalities display a sustainable pattern, meaning that their average annual capacity to store water is enough to satisfy the total demand. The alpine municipalities display greater sustainability since their capacity to yield the water is higher while the demand is low (few inhabitants and no consumption for agricultural uses).

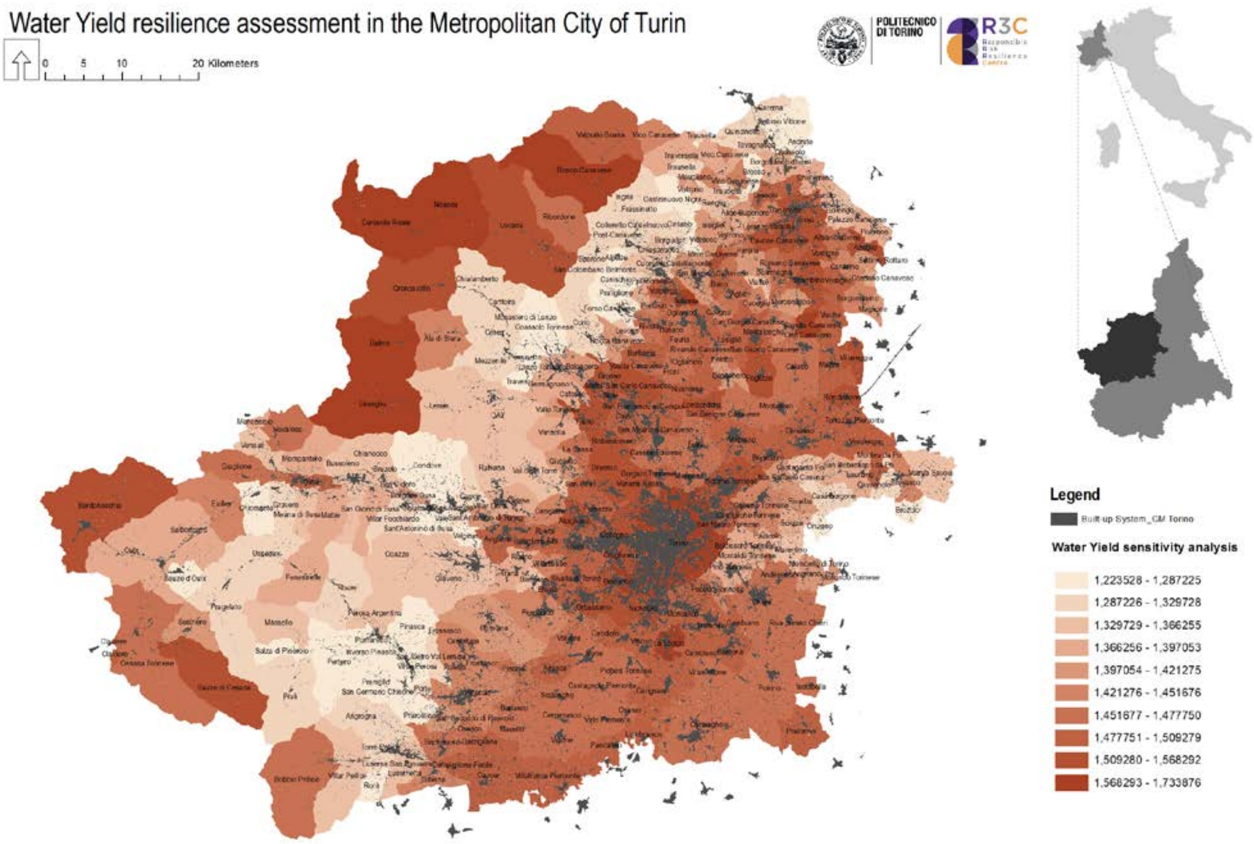
3.2 An ES indicator of resilience

Using the output of the before-mentioned Water Yield model, the assessment of resilience overpassed the simpler assessment of "sustainability" considering that it must to be evaluated how the Natural Capital "react" to a specific pressure (exposure/vulnerability) and for pre-determined scenarios (time consideration). Therefore, here the resilience can be improved through the Water Yield ES provisioning under specific events (McPhearson, Hamstead and Kremer, 2014; McPhearson *et al.*, 2015). In that case, it has been considered that the Water Yield model run setting the rainfall parameter at 400 mm/year instead of being

settled at 800 (400 mm/year is the lowest registered precipitation according to the historical series of annual rainfall precipitation events; thus it has been used a proxy of a “dry season”).

The Water Yield model has been re-settled using the new input, and the output has been evaluated looking how was the degree of variation (it is expected that halving the rainfall also the water yield is halved and, if not, where this value is higher or lower of the 50%). The hypothesis is that a system which is sustainable maybe turn out not to be resilient and vice-versa.

Figure 4 – The Water Yield resilience (source: author’s elaboration)



The output has been ranked using the rate of variation between the original water yield value (input rain 800 mm) and the new water yield value (input rain 400mm).

The variation has been calculated using this formula:

$$var = \frac{Xf - Xi}{Xi} * 100$$

Where: Xf is the amount of water yielded in a municipality with 800 mm of rainfall and Xi is the amount of water yielded in a municipality with 400 mm.

Variations, ranges from a maximum of – 87%, to a minimum of – 61% (mean: -0,71%)

This indicates that the model is highly sensible to the precipitation, since all the municipality displayed a change above the 50%. A sensitivity test confirmed this hypothesis whereas the sensitivity, calculated as the registered variation on the input variation using the follow formula:

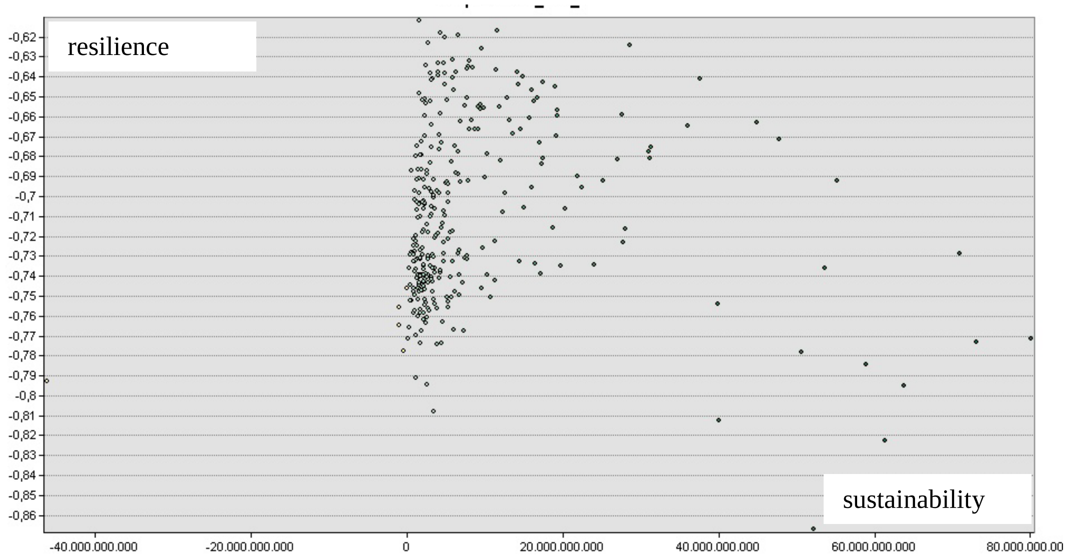
$$sens = variation \frac{output}{input}$$

indicates that all municipalities are highly sensible to the variation of rainfall parameter.

To test how the two models are comparable or not a correlation matrix has been displayed to understand if sustainability and resilience displays similar patterns or not.

To do this, the two indicators where joined together in a new shapefile, and compared with a statistical analysis using ESRI ArcGis 10.6.

Graph 1 – Correlation between sustainability and resilience (source: author's elaboration)



The distribution of the new file has been observed through a matrix graph of the value's distribution.

It is expected that if sustainability and resilience display similar patterns, the more a municipality is sustainable, the more is also resilient. Therefore, the typical distribution of correlated variables is the ones where the dots are concentrated along the diagonal axes from low to high values.

In the graph 1, the values of sustainability are represented in the "x" axes, and their range reflects the degree of sustainability measured as the quantity of water that is yielded by a municipality less the fraction of the consumption: the more the value rise and the more the provision of this specific ES is sustainable. On the "y" axes the degree of resilience is represented by the rate of variation between the ES water yield capacity against the testing scenarios of climate change: in this case, the values are higher on the bottom and decreases on the top of the axes since the lower change means a better resilient capacity.

Looking at the dot distribution, there is a vertical flattening of the points for lower values of sustainability meaning that the resilience displays a pattern independent to the sustainable conditions of the territory.

As the figure well-describes, there is no correlation between the variables since the sustainability is not related with the resilience. The statistical correlation confirms this pattern, with a value of -0.048 (positive or negative correlation displays significant values above the 0.5 value or below the – 0.5) which demonstrates that there is no significant positive or negative correlation between the two.

4. Discussion and conclusions

This paper discussed how the assessment of resilience needs to be supported by specific methodologies which differ from the most traditional measures of sustainability.

An empirical example of Water Yield ES assessment conducted in the area of the Metropolitan City of Turin confirmed that the measure of sustainability and the measure of resilience could be obtained through two different methodologies. Besides, it is demonstrated that the results didn't overlap thus indicating that

resilience differs form of sustainability not only at the linguistic and epistemological level but also at the empirical/quantitative level.

Therefore, the interpretation and the utilisation of sustainability or resilience indicators can conduct significant different results.

As earlier mentioned, the term resilience is nowadays under the definition, and its significance assumes the perspective of the primary discipline that undergoes its assessment. Since urban planning is a multidisciplinary field, it is requested that from definition to its measurement, the resilience assumes a well-defined methodology. To what concerns urban planning, urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to return to desired functions in the face of a disturbance, adapting to change (Meerow and Newell, 2016; Meerow, Joshua P Newell and Stults, 2016). Such definition requires that the concept of rebound, the non-dynamic equilibrium (Holling, 1996) the elasticity, of the system, is measured with indicators that incorporate the changes of the system under defined conditions.

This empirical, experimental work is still under testing conditions to see if similar results are displayed in other broader context. In the future, the methodology will be tested against another target area: the Upper Chattahoochee (Atlanta, USA) using the same parameters and the same approach of measuring.

If the results confirm their relevance, a step forward in the measurement of a complex and dynamic indicator will help planners in their systematic assessment of territorial resilience, giving them the possibility to address specific policies to reach a better condition for citizens and local communities.

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