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multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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Multisectoral comprehensive planning and design along the Disaster Risk Management cycle

DV 5.4.1

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Technical References

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* PU = Public

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Technical References

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1. Setting the framework

As cities encounter an increasing array of challenges and stressors, such as climate change, natural hazards, and rapid urbanization, the concept of resilience is gaining growing attention in urban and regional development and planning. These challenges are indeed becoming more complex and unpredictable, making it imperative for cities and metropolitan territories to develop strategies that enhance their ability to absorb shocks, recover from crises, and adapt to evolving circumstances. In this context, over the years, the concept of resilience has emerged as a "new way of thinking" (Folke, 2006) across different fields of expertise, including environmental science, sociology, urban and regional planning, engineering, and public policy. Globally, various public institutions (but also non-profit organizations) have embraced resilience-based planning, also according to the UN 2030 Agenda for Sustainable Development, extending to local initiatives.

The concept of resilience finds one of its most significant and applied expressions within the field of Disaster Risk Management (DRM). As urban environments face increasing environmental, social, and economic stresses, DRM emerges as a pivotal mechanism for operationalizing resilience through the development and implementation of strategic and temporal interventions. In this context, DRM serves as a bridge between resilience theory and practice, translating abstract concepts into actionable measures that address both immediate and long-term risks. As required by global frameworks such as the Sendai Framework for Disaster Risk Reduction (2015) and the UN 2030 Agenda for Sustainable Development, DRM contributes fundamentally to the enhancement of resilience. The United Nations Office for Disaster Risk Reduction (UNDRR, 2017) defines DRM as "the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk, and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses". This comprehensive approach underscores the temporal dimension of DRM, which encompasses four interrelated stages (prevention and mitigation, preparedness, response, rehabilitation and recovery), each of which plays a crucial role in enhancing resilience across different time scales.

Building on this foundation, the concept of urban resilience has emerged as a key paradigm within urban and regional planning, offering a context-specific application of resilience thinking and DRM principles to the unique challenges faced by cities and metropolitan areas. The notion of urban resilience arose from the broader interest in resilience among planners and researchers (Davoudi et al., 2012). The rising prominence of urban resilience is reflected in the expanding body of literature on the topic. Furthermore, this growing focus has led to the integration of resilience-based policies in urban and metropolitan governance, disaster risk management, infrastructure development and planning. Ultimately, resilience can be a powerful and transformative concept that has the potential to reframe various planning practices and interventions (Datola, 2023).

In this context, another relevant concept is transformative resilience (Giovannini et al., 2020), which involves harnessing disturbances as catalysts for positive change and innovation (Asadzadeh et al., 2022). Urban systems continuously adapt and learn from disturbances to enhance their capacity for overcoming future shocks (Sharifi & Yamagata, 2018). By incorporating also the concept of transformative resilience into planning practices and interventions, a more comprehensive and forward-thinking approach to building resilient urban environments can emerge. Such a new perspective advocates for systemic changes that prioritize radical and nonlinear transformations in the urban fabric, fostering continuous adaptation and evolution. Resilience is seen as a dynamic force driving institutional, organizational, and social change rather than just passive resistance. Achieving this requires an interdisciplinary approach that leverages diverse fields to promote systemic modification and adaptation. Flexibility and responsiveness are essential characteristics of governance needed to effectively implement these transformative resilience strategies over the medium-to-long-term at multiple levels across sectors (Brunetta et al., 2019; Brunetta & Voghera, 2017).

However, the absence of a widely recognised definition of resilience applied to urban contexts makes it difficult to understand their complexity. In this context, the notion of urban resilience is useful due to its multifaceted nature that encompasses the ability of cities to withstand and recover from acute shocks and chronic stresses. A widely accepted definition for urban resilience is given by Meerow et al. (2016): "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 quickly transform systems that limit current or future adaptive capacity". This definition highlights the interconnected nature of urban resilience, emphasizing the relevance of adaptability and transformation. Additionally, urban resilience does appear as a complex issue that must consider all the different dimensions of an urban system. These dimensions include, for example, governance frameworks, built and infrastructure development, economic stability, environmental sustainability, and social cohesion. To understand the complexity of an urban system, it is necessary to address all these dimensions (Sharifi & Yamagata, 2016). However, the vast and often unclear body of literature on resilience does not help to clarify the resilience level of a city or a metropolitan territory.

Despite its widespread recognition in academic literature, implementing resilience remains a challenging endeavour. This difficulty stems from the inherently multidisciplinary and complex nature of the concept—particularly in urban and territorial contexts—where resilience serves as a broad and evolving framework (Beltramino et al., 2022).

The emphasis on adaptability and maintaining essential functions aligns with the idea of resilience as an ongoing process, where territories continuously learn and evolve to enhance their capacity for future shocks.

This perspective lays the groundwork for practical applications and interventions aimed at building and enhancing urban resilience.

2. Methodology to evaluate resilience

Indeed, it is possible to trace the absence of universally accepted metrics or standardized assessment frameworks, making it challenging to measure the value of resilience of a city or a metropolitan territory and compare this value across different cities and regions. Traditional methods for evaluating urban resilience tend to focus on specific risks or often lack a holistic perspective. Thus, measuring urban resilience is a complex and evolving field that requires a multidimensional approach.

This research argues for a more holistic approach to operationalize the concept of resilience in urban planning that remains an open question due to the lack of empirical knowledge on measuring the degree of resilience. It encompasses identifying relevant dimensions selecting measurable indicators, and collecting data to evaluate a city's strengths and weaknesses across different resilience capacities.

By analyzing the existing body of literature on urban resilience, this research aims to understand and collect the metrics and indicators used to measure urban resilience and provide a comprehensive understanding of the concept and its implications for future urban development and planning.

2.1 From literature review to the proposal

The literature review was firstly conducted using a keyword-based search technique within the Scopus database. Specific search terms were formulated to refine the focus and identify a targeted set of studies for a comprehensive review of the field. Two separate strings were developed: the first included indicator-related terms, and the second included keywords related to urban resilience assessment, evaluation and measurement. While the indicators-focused string identified studies that explicitly discussed measurement tools, the assessment-focused string captured broader discussions of assessment methodologies.

The combined search strings resulted in a rich dataset of 965 unique records. To ensure a manageable number of documents for in-depth analysis, the search results were then further refined. This involved adding a search based on author-specified keywords, a critical step in limiting the results to papers with a primary focus on urban resilience assessment, rather than simply mentioning the concept. Additional filters were applied to further refine the search results and ensure selection of the most relevant literature. These filters included year of publication, document type, language and subject area, as detailed in Figure 1.

After applying the filters, the number of unique records was reduced to 141. Of these, 71 papers were identified as resulting from both strings. These 71 papers then underwent rigorous screening. Finally, based on the presence of specific resilience indicators, 39 papers were selected for inclusion in the literature review (appendix A).

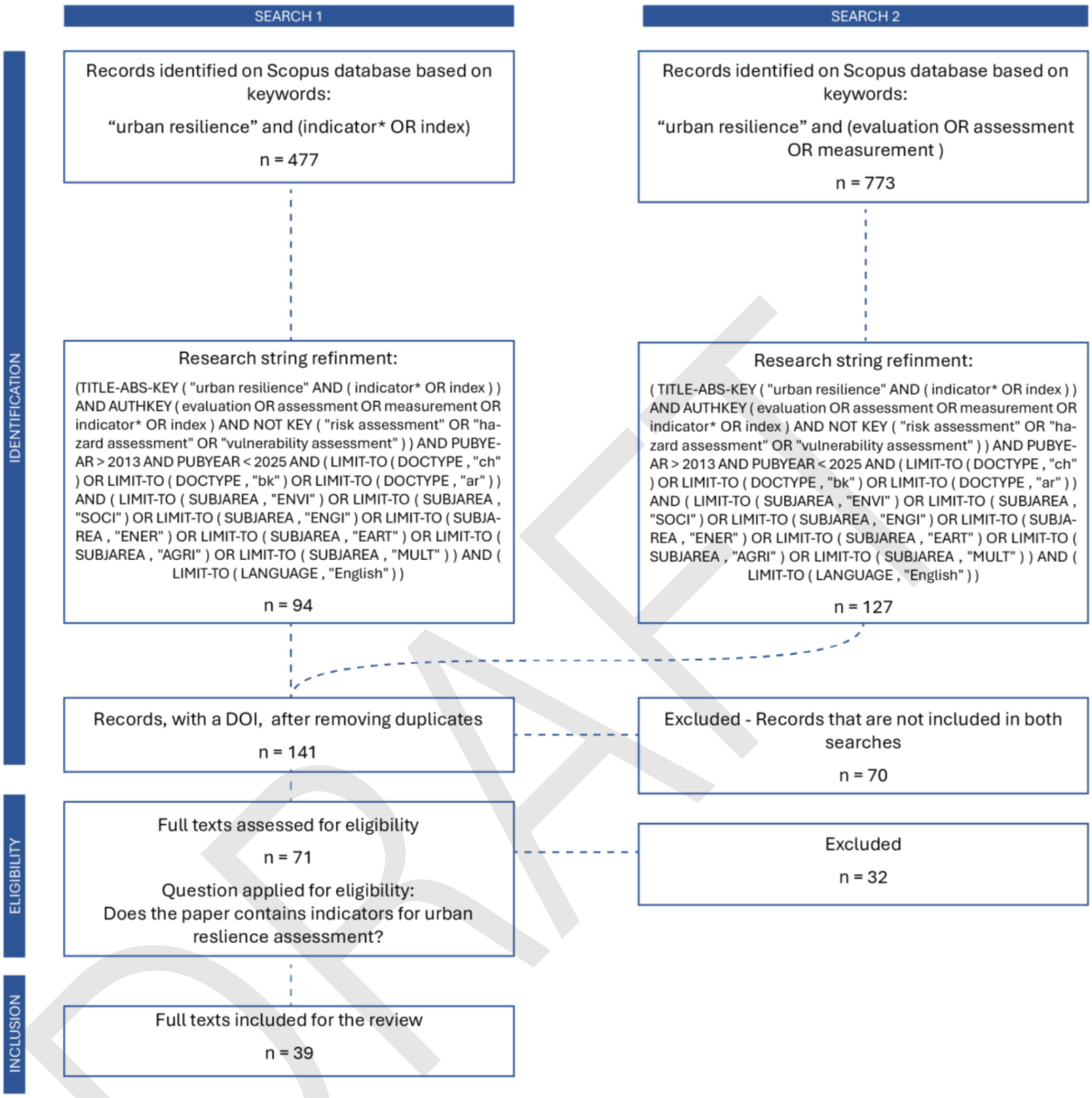

Figure 1. Literature review workflow

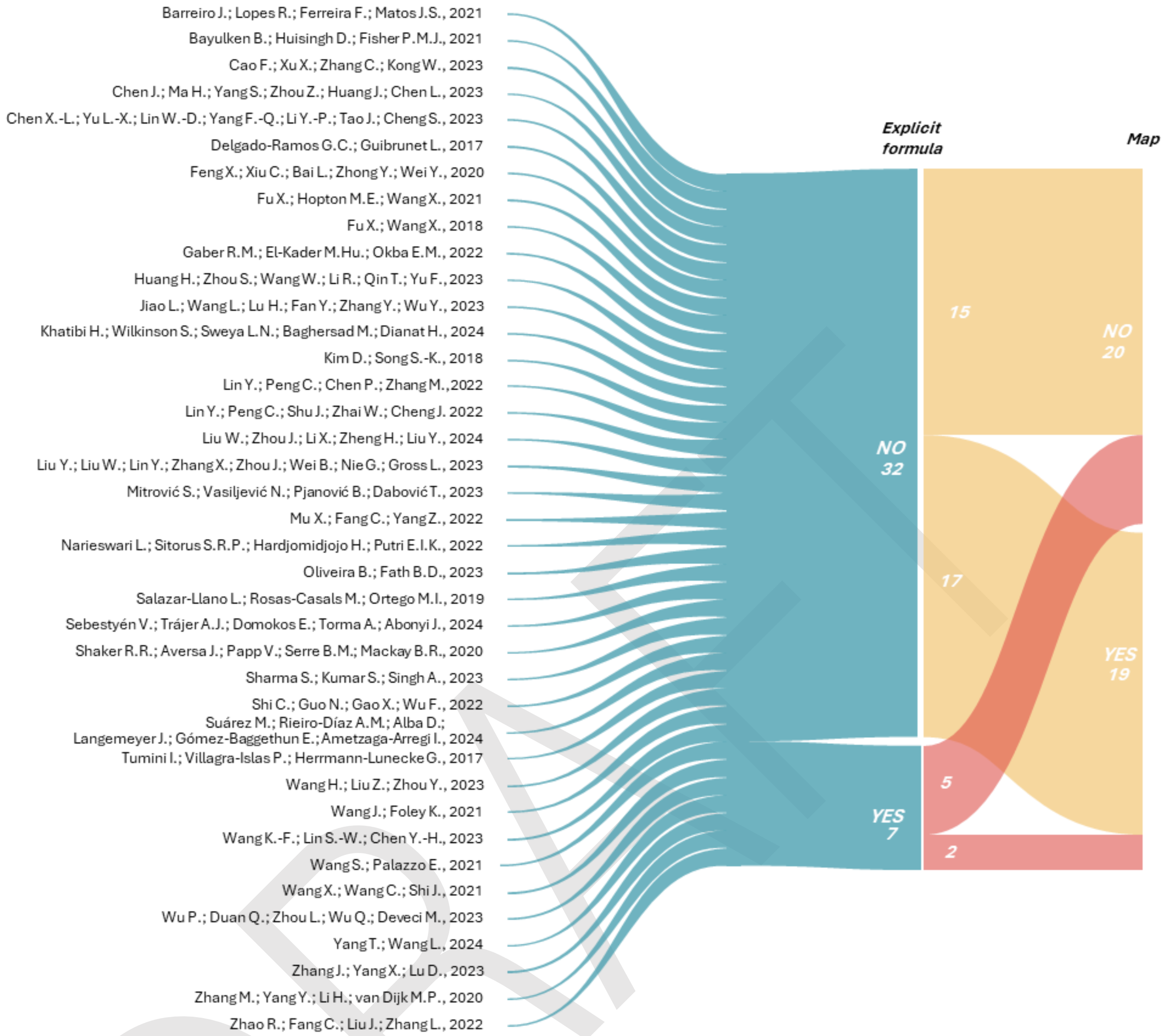

Figure 2. Papers including a map and/or a formula

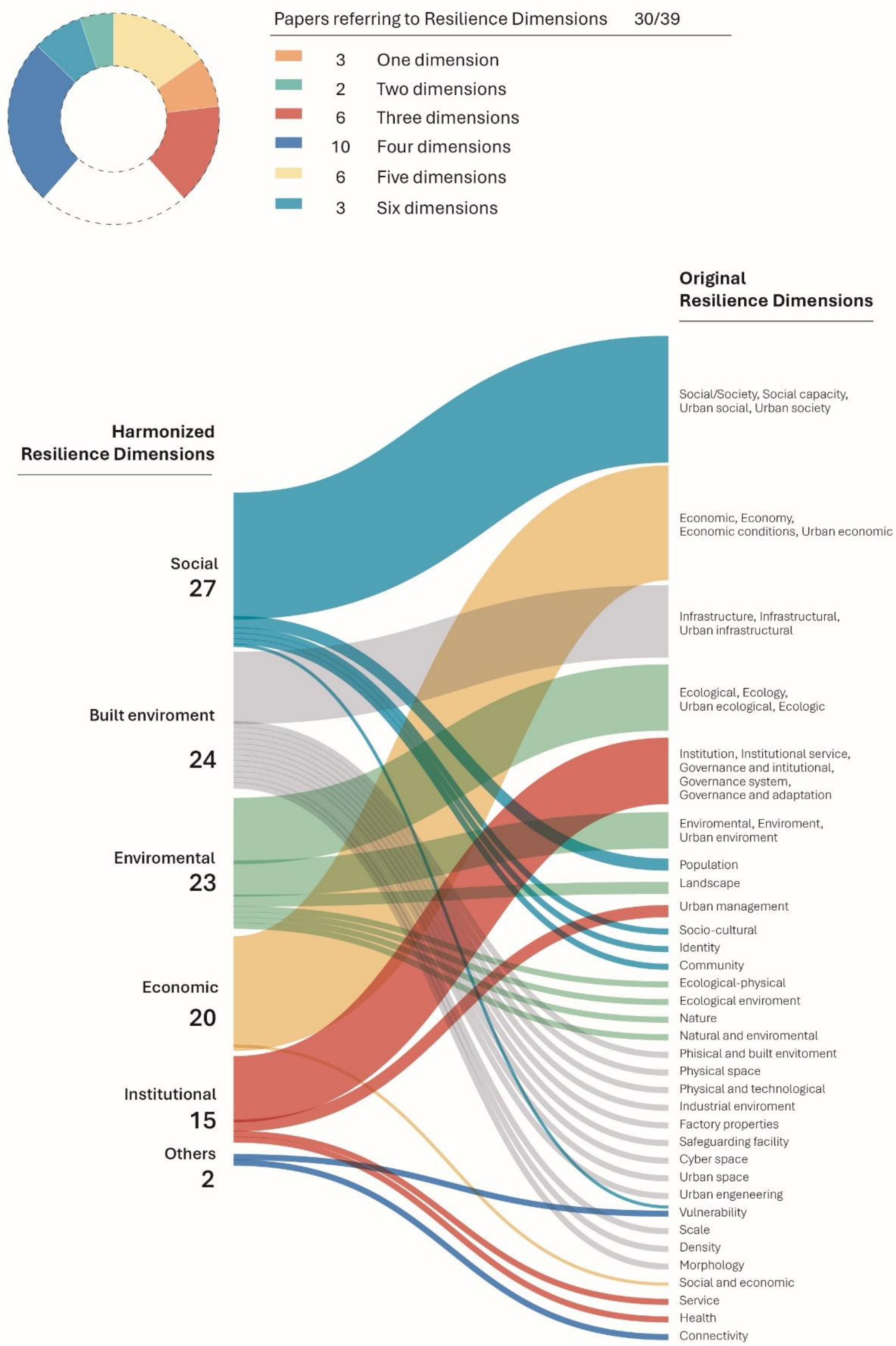

Figure 3. Papers classified by resilience dimensions

2.2 Reorganization of the taxonomy

A significant portion of existing research neglects the holistic nature of urban ecosystems (Rus et al., 2018). This results in assessments that are limited to specific systems, failing to capture the complex interplay between environmental, social, and economic aspects of urban resilience. The prevalent approach of focusing on selected urban components when assessing resilience in the face of specific disasters generates incomplete results (Rus et al., 2018).

This research aims to integrate the different dimensions of the urban system into a single framework for measuring resilience.

Based on the taxonomy proposed in WP 5.2.1, we propose an integration and re-organisation of the urban components considered according to five dimensions of resilience: the built environment, the environmental dimension, the social dimension, the economic dimension and the institutional dimension (Figure 2).

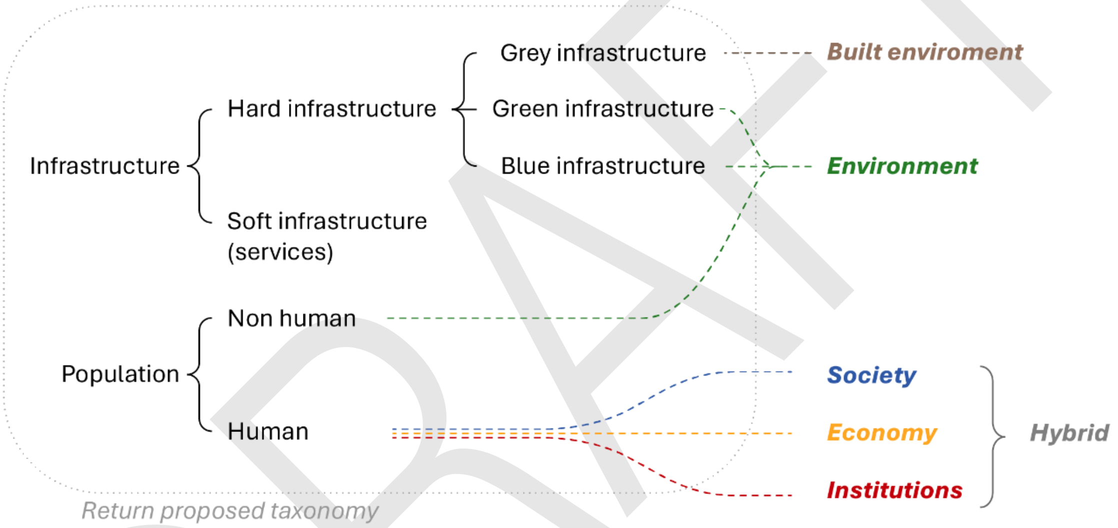

Figure 4. Re-organization of the taxonomy proposed by WP 5.2.1

Each dimension plays a significant role in enhancing a city's resilience (Chen et al., 2019; Ostadtaghizadeh et al., 2015; Patel & Nosal, 2016; Ribeiro & Gonçalves, 2019):

- *Bult environment*
  This dimension of urban resilience focuses on the built environment and infrastructure of a city. It examines the capacity of physical structures, such as buildings, transportation systems, and utilities, to withstand and recover from acute shocks, including natural disasters and infrastructure failures. This dimension also encompasses the importance of resilient urban design and architecture to mitigate the impact of external hazards and ensure the safety and functionality of urban spaces (Ahern, 2011; Desouza & Flanery, 2013; Sharifi & Yamagata, 2016; Spaans & Waterhout, 2017; Tyler et al., 2016)

- *Environmental dimension*

The environmental dimension of urban resilience involves the city's ability to mitigate and adapt to environmental risks and challenges such as natural disasters, climate change, and pollution. It includes the preservation of green spaces, sustainable land use planning, measures to protect air and water quality, preserving and restoring natural ecosystems, implementing sustainable resource management practices, and reducing environmental risks to enhance a city's overall resilience to environmental stressors (Sharifi & Yamagata, 2014; Spaans & Waterhout, 2017; Tyler & Moench, 2012).

- *Economic dimension*

The economic dimension of urban resilience focuses on the financial stability and adaptive capacity of cities in the face of economic shocks and disruptions. It includes strategies for economic diversification, job creation, and investment in resilient business practices, aiming to build a robust economy that can withstand and recover from economic downturns and crises (Desouza & Flanery, 2013; Sharifi & Yamagata, 2014; Spaans & Waterhout, 2017; Tyler et al., 2016)

- *Social dimension*

The social dimension underscores the importance of community cohesion, social equity, and inclusivity in building resilient cities. It involves fostering strong social networks, promoting community engagement, and addressing social disparities to ensure that all segments of the population can effectively cope with and recover from social and economic challenges (Ahern, 2011; Allan & Bryant, 2011; Desouza & Flanery, 2013; Sharifi & Yamagata, 2014; Spaans & Waterhout, 2017; Tyler et al., 2016)

- *Institutional dimension*

The institutional dimension of urban resilience revolves around governance, policy frameworks, and institutional capacities. It assesses the effectiveness of urban governance structures, emergency response mechanisms, and regulatory frameworks in facilitating coordinated and efficient responses to crises and in enabling long-term resilience planning and implementation (Coaffee, 2008; Desouza & Flanery, 2013; Leichenko, 2011; Sharifi & Yamagata, 2014; Spaans & Waterhout, 2017; Tyler & Moench, 2012).

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3. Catalogue of progress indicators for resilience measurement

3.1 Selection criteria

The evaluation of the resilience capacity is based on an interdisciplinary approach dealing with the literature review (n. 39 documents, 970 indicators). Starting with the taxonomy (Wp2), the catalogue of indicators is composed of a set or a series of indicators/indexes that can be used to evaluate the conditions of the built environment, and the environmental, economic, social and institutional characterisation of territories. In fact, considering each of the disciplines involved, the topic of resilience capacity evaluation is quite complex: there are different indicators for different "taxonomy field", and diverse goals and types of applications. The method can focus on many other dimensions of the resilience capacity of a socio-ecological system, using one of the possible assessment/evaluation techniques (from qualitative to quantitative one). The set of indicators/indexes can be used for "interpreting" the state of art or the possible transformation scenario, and monitoring and measuring conditions and processes.

Besides the indicators/indexes can be used to "evaluate the resilience functions", quantifying the condition, considering the processes and the human and institutional actions/policies and their effects on territorial resilience; the objective is to evaluate the resilience capacity to define policy at territorial scale, and on the local scale and the district scale. This kind of indicators or indexes can be applied to orient specific "resilience capacities/functions", supporting policy actions. All these functions are well represented in the phases of the SEA process: screening, scoping, monitoring.

However, "A compatible set of indicators may be difficult to achieve and, frequently, the assessment process may reveal inconsistencies" (Fischer, 2007, p. 40).

The following catalogue shows a full list of the indicators/indexes proposed for each profile of conditions of the built environment, and the environmental, economic, social and institutional conditions of territories.

The choice of suitable indicators/indexes from the catalogue may vary based on the local conditions of each case studies/POC. Still, the choice also depends on:

1. the **type of application,** from assessment of the actual resilience capacity – the state of the art – to the evaluation of the possible scenario of transformation related to planning aims or to diverse institutional policies.
2. the **characteristics of the territory** and the conditions of the built environment, and the environmental, economic, social and institutional conditions and the relevant territorial risks and vulnerabilities.
3. **the presence of existing and/or implemented databases** to have a good level of transferability.

The territorial conditions that we will measure should be applied at district scale, but to contribute to policy indication/policy design the evaluation and the catalogue should be flexible, and it can be used at different levels, from region to local, which correspond to the two levels for processing territorial policies and plans.

3.2 Indicators proposal

This refined set of indicators will serve as a valuable tool for assessing and improving the resilience of urban areas in different contexts.

Starting from the 39 papers included in the literature review database, 970 indicators were collected and analysed, gathering for each of them the following information, when available: indicator name and possible sub-indicators, resilience dimension, direction (positive/negative), formula, unit of measure, definition, references.

Indicators with similar meanings were grouped to easily find redundancies and eliminate duplicates. While indicators can share similar concepts, they can be described with different wording, units or equations. For example, indicators such as 'permeable surfaces' and 'imperviousness' represent the same concept but are described in opposite directions (positive/negative).

Then, this extensive set of indicators underwent a group discussion and review. The various information were harmonized to create a unified version for each indicator that best suits the final goal of measuring resilience. It is important to note that the indicators derived from the literature review served as the basis for this process but have been extensively modified and refined for the final version of the catalogue. In addition, indicators that were considered irrelevant to the research objectives were excluded.

This process led to a more manageable and reasonable set of 87 indicators. However, it became clear that some topics were under-represented or missing, needing additional integration to the catalogue. To fill these gaps, 21 additional indicators were included, drawing from the expertise of the research group members, their knowledge and their past and ongoing experience, resulting in a comprehensive catalogue of 108 indicators.

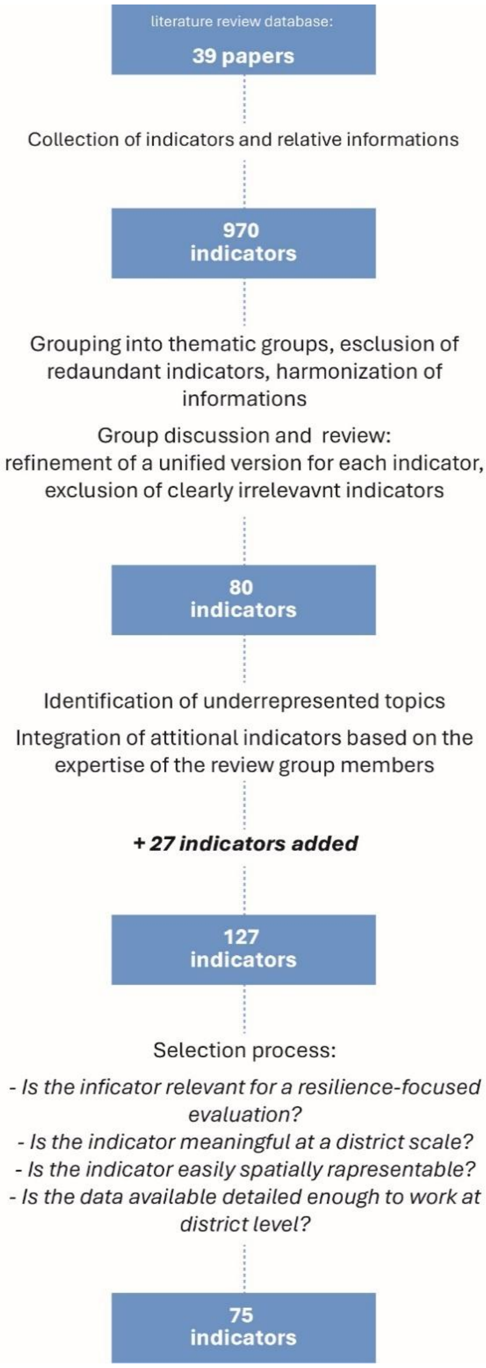

Figure 5. Process of selection

The following attributes describe each indicator:

- *Resilience dimension*: The dimensions of resilience addressed by the indicator. These include environmental, built environment, social, economic and institutional dimensions. A single indicator can cover one or more dimensions.
- *Topic*: Thematic categories including buildings, cooperation, demography, ecosystem services, emergency, heritage, income, infrastructure and networks, land use, landscape, natural/green spaces, planning and programming, pollution, resources/resource consumption, and services.
- *Definition*: A short explanation of the indicator.
- *Frequency*: The occurrence of the indicator in the analysed literature.
- *Source ID*: Identification number of the source from the literature database.
- *Direction*: Whether the indicator has a positive or negative effect on resilience.
- *Formula*: The mathematical representation, when possible.
- *Unit of measurement*: The unit in which the indicator is measured.
- *Minimum Territorial Scale*: The smallest geographical unit for which the indicator is meaningful.

At this stage, a selection was made based on the relevance, calculability, and spatial applicability of the indicators. The following exclusion criteria were applied:

1. *Not aligned with an urban resilience-focused evaluation*: Indicators related to risk, vulnerability assessment, or sustainability rather than resilience;
2. *Not relevant at the district scale*: Indicators not meaningful at the district level, but at smaller or bigger scales;
3. *Difficult to spatially represent*: Indicators that cannot be easily mapped (with GIS);
4. *Data not readily available at the district scale*: Indicators without consistent data sources for a district-level application.

The application of these selection criteria led to a refined version of catalogue, composed of 76 indicators, comprising 60 indicators drawn from the Scopus literature review and 16 additional indicators.

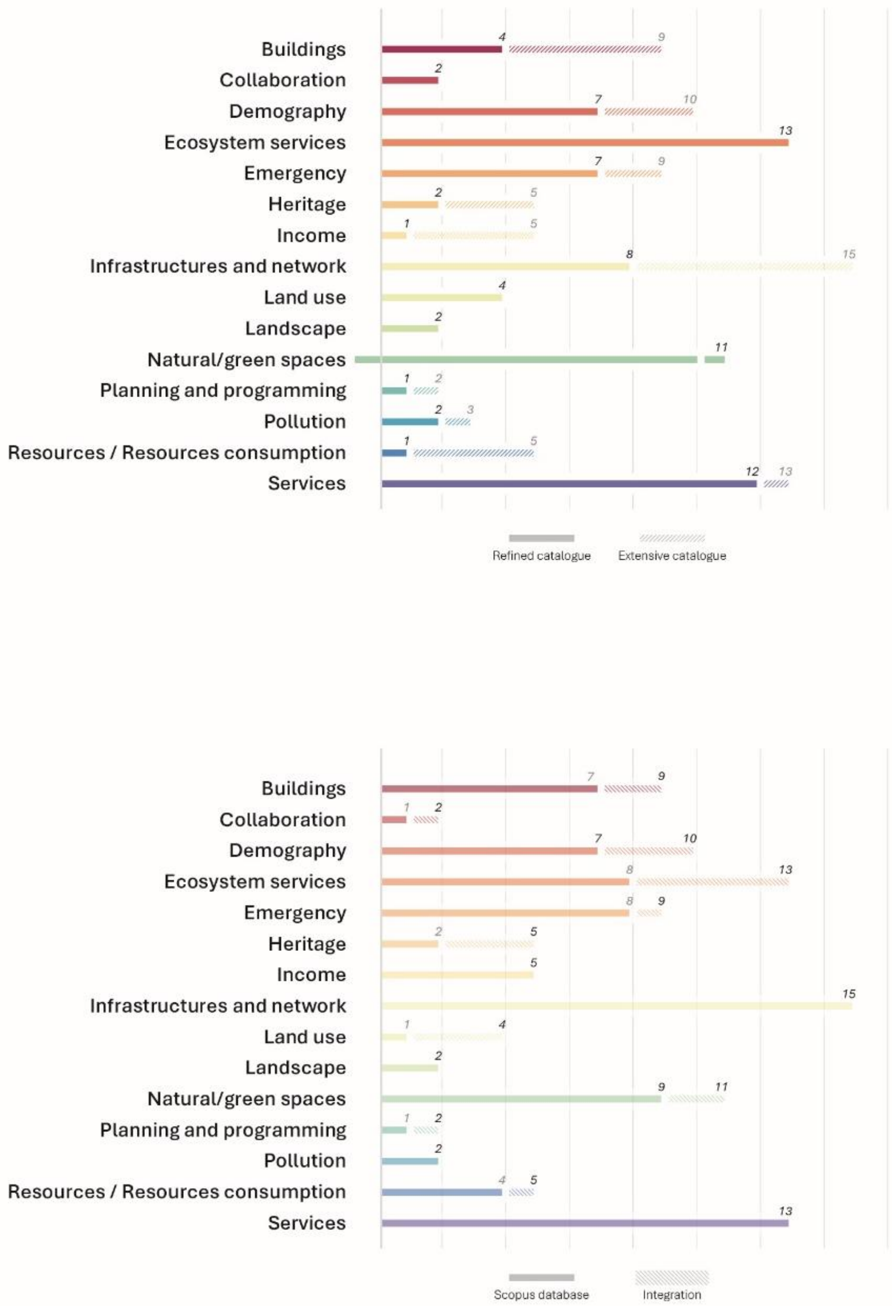

Figure 5. Indicators in the Refined catalogue, in the Selected Catalogue and Integrations, classified by topic

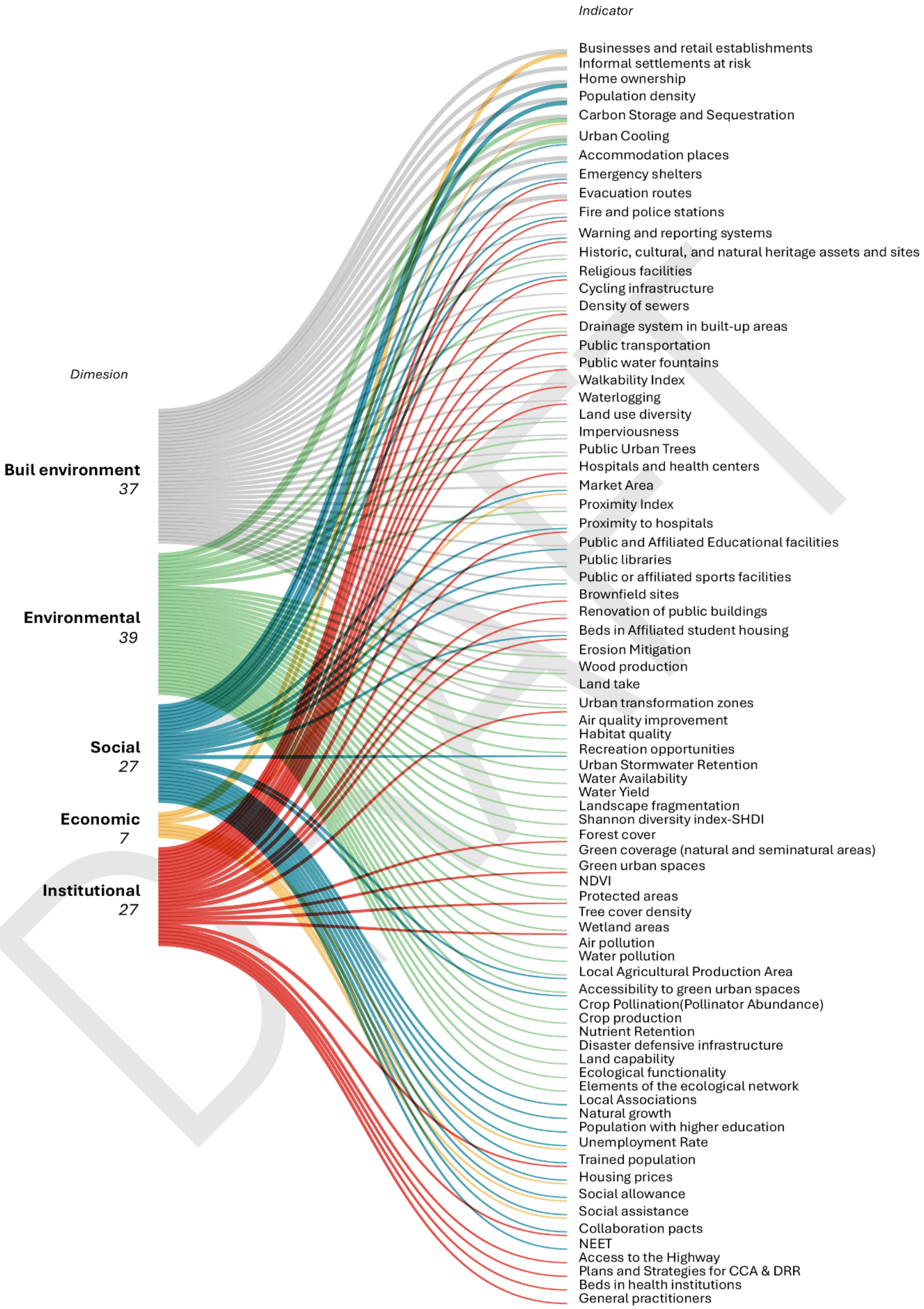

Figure 7. Indicators grouped by Dimensions

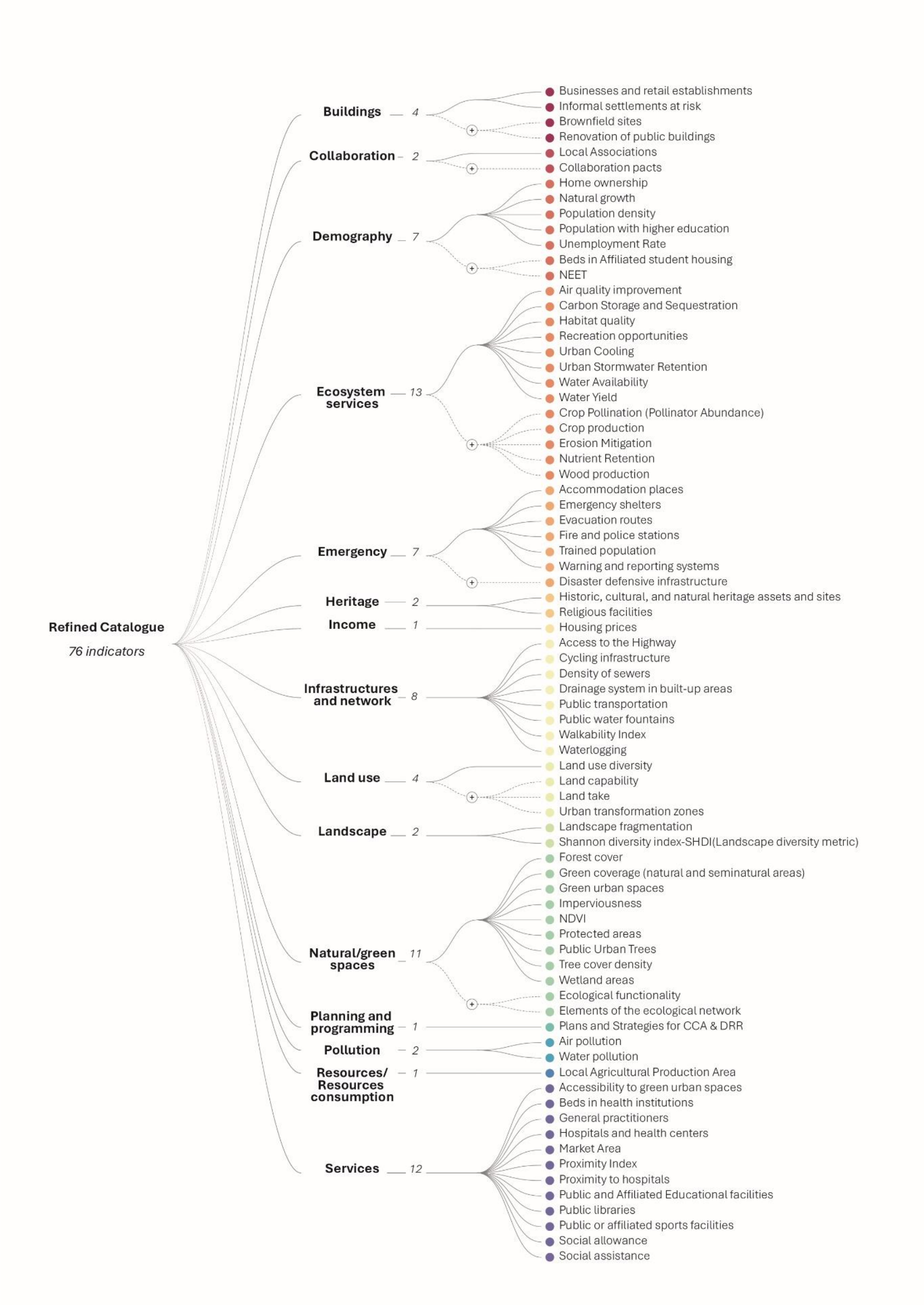

Figure 8. Indicators grouped by Topic

Table 1. Selected Catalogue

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x					1	**Building density**	Buildings	Density of buildings within a selected area expressed with the Floor area ratio (ratio of a building's total floor area to the size of land upon which it is built)	2	97, 182	negative	$N = \frac{A_s}{A_t}$ *N = floor area ratio (building density)* A_s *= total floor area of the building (the sum of all floor spaces in the building)* A_t *= the size of the parcel upon which the building is constructed*	%	sub-district
x			x		2	**Businesses and retail establishments**	Buildings	Concentration of sales facilities - categorized by size when possible - in relation to the resident population	1	214	positive	$N = \frac{S}{R}$ *N = business and retail establishments* *S= number of sales facilities in the selcted area* *P = total population in the selected area*	unit/10,000 inh.	district
x					3	**Energy performance of buildings**	Buildings	Energy efficiency of the existing building stock	1	30	postive	$N = \frac{O}{C}$ *N = energy performance* *O = amount of output the appliance delivers per unit area, per year* *C = amount of energy it consumes to deliver this output per unit area per year*	%	sub-district
x					4	**Informal settlements at risk**	Buildings	Surface occupied by informal settlements (nomadic camps, illegal camps...) in high-risk areas	2	30, 179	negative	$N = \frac{A_i}{A_t}$ *N = informal settlements at risk* A_r *= area occupied by informal settlements in high risk area* A_t *= total surface of the selected area*	%	district
x	x				5	**Major accident hazard establishments**	Buildings	Presence of estabilishments that fall into the Seveso-III EU Directive	1	187	negative	$N = \frac{A_S}{A_t}$ *N = major accident hazard establishment* A_S *= surface of the Seveso zone* A_t *= total surface of the selected area*	%	urban
x					6	**Buildings completed after 1971**	Buildings	Percentage of buildings completed after 1971, the year when the seismic safety law was enacted in Italy, compared to the overall building stock in a selected area.	2	58, 214	not defined	$N = \frac{A_b}{A_t}$ *N = proportion of buildings built after 1980* A_r *= area occupied by buildings built after 1980* A_t *= tortal area of the building stock*	%	sub-district
x			x		7	**Industrial area**	Buildings	Proportion of industrial areas within a selected area	1	187	not defined	$N = \frac{A_i}{A_t}$ *N= proportion of industrial area* F_t *= sum of surface of factories in the selected area* A_t *= total surface of the selected area*	%	district
		x			8	**Local Associations**	Collaboration	Number and location of active local associations	2	173, 214	positive	$N = \frac{L}{A_t}$ *N= local associations* *L = number of local associations in the selcted area* *P = total population in the selected area*	unit/10,000 inh.	sub-district
		x			9	**Certified disabilities**	Demography	Proportion of individuals who have been officially recognized and documented as having a disability by relevant authorities compared to the population of a selected area	2	179, 214	not defined	$N = \frac{D}{P}$ *N = certified disabilities* *D = inhabitants with certified disabilities* *R = total population in the selected area*	%	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x		x			10	**Home ownership**	Demography	Proportion of households that own their residence compared to those who rent or occupy their homes through other means within a selected area	4	11, 126, 179, 214	positive	$N = \frac{O}{H}$ *N = home ownership* *O= number of home-owning households* *H= total number of households*	%	district
		x	x	x	11	**Minimum living standard**	Demography	Proportion of the population receiving the minimum wage in the city	1	149	negative	$N = \frac{M}{P_w}$ *N= minimum living standard* *M= number of inhabitants receiving minimum wage* *P_w = total working-age population*	%	sub-district
		x			12	**Natural growth**	Demography	Difference between the number of births and the number of deaths in a given population over a specific period. It measures the organic increase or decrease in population size, excluding migration	7	37, 48, 86, 100, 120, 177, 214,	positive	$N = CBR - CDR$ *N = Natural Growth or Natural Increase Population (NIP)* *CBR= Crude Birth Rate* *CDR= Crude Death Rate*	count	district
x		x			13	**Population density**	Demography	Number of resident people per unit of area	14	11, 30, 31, 64, 97, 100, 103, 120, 126, 149, 173, 182, 191, 214	negative	$N = \frac{P}{A}$ *N = density of resident population* *P= inhabitants in the selected area* *A= total surface of selected area*	unit/km^2	sub-district
		x			14	**Population with higher education**	Demography	Proportion of the population with higher education	4	58, 64, 97, 214	positive	$N = \frac{H}{P}$ *N = population with higher education* *H = inhabitants with higher education* *P = total population in the selected area*	%	sub-district
		x	x		15	**Unemployment Rate**	Demography	Number of beds in various medical and health institutions compared to the resident population whithin a selected area	14	36, 37, 48, 62, 64, 86, 97, 126, 131, 149, 152, 173, 177, 214	negative	$N = \frac{U}{P}$ *N = unemployment rate* *U = number of urban registered unemployed* *P= total population in the selected area*	%	urban
	x				16	**Air quality improvement**	Ecosystem services	Hourly amount of pollution removed by the urban forest, and associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter 2.5 (<2.5 microns).	3	9, 21,150, 223	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x		x		17	**Carbon Storage and Sequestration**	Ecosystem services	Amount of carbon retained in ecosystems, primarily in vegetation, soils, and wetlands	3	9, 44, 178, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district
	x				18	**Habitat quality**	Ecosystem services	This supporting ecosystem service assesses the quality of natural ecosystems for maintaining biological and genetic diversity on Earth	3	21, 44, 150, 216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x	x			19	**Recreation opportunities**	Ecosystem services	Predictions on the spread of person-days of recreation, based on the locations of natural habitats and other features that factor into people's decisions about where to recreate	1	44, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x	x			20	**Urban Cooling**	Ecosystem services	Heat mitigation based on shade, evapotranspiration, albedo, and distance from cooling islands. The index is used to estimate a temperature reduction by vegetation	1	21, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district
	x				21	**Urban Stormwater Retention**	Ecosystem services	Provides information on two ES related to stormwater management: runoff retention, and groundwater recharge	3	21, 36, 150, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district
	x				22	**Water Availability**	Ecosystem services	This is a regulation ecosystem service provided by aquatic and terrestrial ecosystems, which filter and decompose organic waste entering inland waters and coastal/marine ecosystems, thus contributing to potable water supply	2	21, 44, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	urban
	x				23	**Water Yield**	Ecosystem services	Estimates the relative contributions of water from different parts of a landscape (Annual or seasonal water yield)	2	21, 150, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x		x			24	**Accommodation places**	Emergency	Presence of accomodation places (hotels, hostels, B&B, etc.)	11	11, 48, 62, 86, 100, 103, 120, 149, 152, 173, 214	positive	$N = \frac{A}{P}$ *N= Aùaccomodation places* *P = number of accomodation places (hotels, hostels, B&B...)* *P = total population in the selected area*	unit/1'000 inh.	urban
		x		x	25	**Emergency medical treatment capability**	Emergency	Number of doctors, nurse anche technicians, specifically intended for emergency intervention in the selected area	1	175	positive	$N = D$ *N= emergengy medical treatment capability* *D = number of doctors, nurses and technicians, specifically intended for emergency intervention in the selected area*	count	urban
x		x		x	26	**Emergency shelters**	Emergency	Temporary housing facilities established to provide refuge and support for individuals and families during emergencies	7	11, 31, 36, 126, 175, 187, 191	positive	$N = \frac{E}{S}$ *N= emergency shelters* *E = capacity of temporary housing units available* *P= total population of the selected*	unit/inh.	urban
x				x	27	**Evacuation routes**	Emergency	Designated routes planned to safely guide individuals away from danger zones during emergencies	2	31, 36	positive	$N = \frac{L}{A}$ *N= evacuation routes* *L= lenght of evacuation routes* *A= total surface of the selected area*	km/km^2	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x		x		x	28	**Fire and police stations**	Emergency	Presence of fire departement station and police station	4	36, 58, 182, 187	positive	$N=\frac{S}{P}$ *N = fire and police station* *S = sum of fire and police department station in the selected area* *P = total populaiton of the selected area*	count	district
		x		x	29	**Public Administration Personnel**	Emergency	Number of public administration (e.g. municipality) employees dedicated to managing administrative functions across critical areas (such as health, safety, urban planning, and disaster management)	2	58, 97	positive	$N=\frac{E}{P}$ *N= public administration personnel* *C= number of public administration employees* *P = total populaiton in the selected area*	count/1,000 inh.	urban
		x		x	30	**Trained population**	Emergency	Total amount of water consumed by both the resident population and non-residents in a selected area during a year	2	36, 179	positive	$N=\frac{S}{P}$ *N= trained population* *S = number of inhabitants who have attended safety courses* *P= total population in the selected area*	count/1,000 inh.	urban
x		x		x	31	**Warning and reporting systems**	Emergency	Precence of warning and reporting systems/hazard prediction capable of help in the managing of the emergence	5	36, 126, 175, 179, 214	positive	$N=\frac{W}{A}$ *N= warning and reporting system* *W= number of warning and reporting systems/hazard prediction able to help manage the emergency* *A= total surface of the selected area*	unit/km^2	urban
x	x				32	**Historic, cultural, and natural heritage assets and sites**	Heritage	Number of sites and buildings of historical, artistic, cultural or natural interest that define a community's heritage, such as: assets with natural beauty, geological singularity or historical memory (excluding monumental trees); villas and any historic parks; buildings of aesthetic and traditional value, including historic centers; panoramic beauties and viewpoints.	2	120, 149, developed based on 220	positive	$N=\sum_{k=0}^{n} w_k$ *N= number of sites and buildings of historical, artistic, cultural or natural interest* *w = number of assets with natural beauty, geological singularity or historical memory (excluding monumental trees); villas and any historic parks; buildings of aesthetic and traditional value, including historic centers; panoramic beauties and viewpoints.* *n= total number of the elements consider*	count	sub-district
x		x		x	33	**Religious facilities**	Heritage	Presence of religious facilities/services	2	58, 120	positive	$N=\frac{R}{P}$ *N= religious facilities* *R= number of religious facilities* *P= total population in the selected area*	unit/10,000 inh.	sub-district
		x	x		34	**Disposable income**	Income	Urban disposable income per capita	17	11, 37, 48, 62, 64, 86, 90, 97, 100, 103, 131, 149, 152, 173, 177, 191, 214	positive	$N=I$ *N= disposable income* *I= net income per capita*	€/inh.	urban
			x	x	35	**GDP**	Income	Gross domestic product	5	37,48,90,103,191	positive	$N=GDP$ *N=Gross Domestic Product:* *GDP= Consumption + Investment + Government Spending + Net Exports*	€	regional

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Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
			x	x	36	**GDP - per capita**	Income	Gross domestic product per capita	13	11,37,48,62,86,97,100,131,149,173,177,191,214	positive	$N = GDP\ per\ capita$ *Groos Domestic Product: GDP= Consumption + Investment + Government Spending + Net Exports*	€/inh.	regional
		x	x		37	**Housing prices**	Income	Market value of housing properties in the residential sector for each territorial zone	1	121	positive	$N = P$ *N= housing prices* *P = average price per square meter referring to residantial buildings*	€/m^2	sub-district
			x	x	38	**Local tax per capita**	Income	Amount of local tax per capita	6	36,37,48,58, 62, 152	not defined	$N = \frac{T}{P}$ *N= local tax per capita* *T = sum of different form of taxes* *P= total population of the selected area*	€/inh.	urban
				x	39	**Access to the Highway**	Infrastructures and network	Population living within a specified distance from a highway entrance or exit	3	100, 130, 173	positive	$N = \frac{Z}{P}$ *N= access to the highway* *H= number of inhabitants within a specified distance from a highway access* *P = total population in the selected area*	%	district
x					40	**Cycling infrastructure**	Infrastructures and network	Extent of bike lanes and shared paths within a selected area	1	30	positive	$N = \frac{L}{A}$ *N= cycling infrastructure* *L = lenght of bike lanes in the selected area* *A = surface of the selected area*	km/km^2	sub-district
x	x			x	41	**Density of sewers**	Infrastructures and network	Surface covered by sewers system over the total area	1	11	positive	$N = \frac{S}{A}$ *N= density of sewers in buit-up area* *S = area covered by sewers network* *A= total surface of the selected area*	%	district
x	x			x	42	**Drainage system in built-up areas**	Infrastructures and network	Surface covered by drainage system over the total area	6	37, 48, 58, 86, 173, 187	positive	$N = \frac{D}{A}$ *N= drainage system in buit-up areas* *D = area covered by drainage system* *A= total surface of the selected area*	%	district
x				x	43	**Fixed-line phones**	Infrastructures and network	Density of fixed phone users within a selected area calculated as the number of fixed phone connections relative to the total resident population	2	126, 173	to be defined	$N = \frac{N}{P}$ *N= fixed-line phones* *N= number of fixed phone connections* *P= total population in the selected area*	unit/inh.	urban
x				x	44	**Gas penetration**	Infrastructures and network	Proportion of area served by a natural gas supply network over the total area	4	86, 97, 173, 214	to be defined	$N = \frac{G}{A}$ *N= gas penetration* *G = area covered by gas network* *A= total surface of the selected area*	%	urban

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x		x		x	45	**Internet users**	Infrastructures and network	Area that is served by broadband internet infrastructure	7	11, 38, 48, 152, 62, 100, 214	positive	$N = \frac{B}{A}$ *N= Internet users* *I= area covered by broadband Internet service* *A= total surface of the selected area*	%	urban
x		x			46	**Mobile phones**	Infrastructures and network	Proportion of mobile phone users to the resident population	8	64, 103, 152, 173, 37, 48, 97, 214	positive	$N = \frac{K}{P}$ *N= mobile phones* *N= number of mobile phone users* *P= total population in the selected area*	unit/10,000 inh.	urban
x		x			47	**Parkings**	Infrastructures and network	Proportion of parking area over the selected area	2	30, 120	positive	$N = \frac{P}{A}$ *N= parkings* *P= surface of parkings in the selected area* *A= total surface of the selected area*	%	sub-district
x				x	48	**Public transportation**	Infrastructures and network	Distribution and concentration of public transport supply, availability and number of public transport stops, encompassing various modes of transportation (buses, trains, trams, etc.)	7	11, 62, 64, 86, 97, 100, 173	positive	Kernel Density formula	unit/m^2	sub-district
x				x	49	**Public water fountains**	Infrastructures and network	Distribution and concentration of publicly accessible water fountains	1	120	positive	Kernel Density formula	unit/m^2	sub-district
x				x	50	**Road area**	Infrastructures and network	Proportion of land allocated to roads (including urban streets, highways, and other transportation pathways) over the total area	2	86, 126	positive	$N = \frac{R}{A}$ *N= road area* *R= area covered by roads* *A= total surface of the selected area*	%	district
x				x	51	**Walkability Index**	Infrastructures and network	It measures the level of mobility and accessibility for pedestrians in a selected area	3	31, 121, 182	positive	Formula depends on the variables considered, which vary according to each specific case	adimension al	sub-district
x				x	52	**Water service coverage**	Infrastructures and network	Proportion of area that has access to a reliable and sufficient supply of drinking water for basic needs	7	11, 30, 37, 48, 86, 97, 215	positive	$N = \frac{W}{A}$ *N= water service coverage* *W= area covered by urban water service* *A= total surface of the selected area*	%	urban
x				x	53	**Waterlogging**	Infrastructures and network	Proportion of areas that are prone of excessive accumulation of water over the total area	1	28	negative	$N = \frac{W}{A}$ *N= waterlogging* *W= area at waterlogging risk* *A= total surface of the selected area*	%	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x	x				54	**Land use diversity**	Land use	Variety and mixture of different types of land uses	2	21, 150	positive	$H = -\sum_{i=1}^{S} pi\ Ln\ pi$ *Pi = (number of polygons of "i" land use classes/ (total number of polygons S)*	adimensional	sub-district
	x				55	**Landscape fragmentation**	Landscape	Degree to which the landscape impedes movement among different patches	1	178, 222	negative	$F = LDI = 1 - \sum_{i=1}^{S} \left(\frac{a_i}{A}\right)$ *LDI= Landscape Division Index* a_i *= area of the iii-th patch* *A = total landscape area*	adimensional	sub-district
	x				56	**Shannon diversity index-SHDI (Landscape diversity metric)**	Landscape	It measures the uniformity of different land use patches within a landscape structure. The higher the value of H, the higher the diversity of species in a particular community	3	121, 178, 36, 222	positive	$H = -\sum_{i=1}^{S} pi\ Ln\ pi$ *Pi = (number of polygons of "i" patches / (total number of polygons S)*	adimensional	sub-district
	x			x	57	**Forest cover**	Natural/green spaces	Proportion of forest coverage over the total area	3	37, 48, 214	positive	$N = \frac{F}{A}$ *N= forest cover* *F = forest area* *A= total surface of the selected area*	%	sub-district
	x				58	**Green coverage (natural and seminatural areas)**	Natural/green spaces	Proportion of green covered areas (natural and seminatural) over the area	5	37, 48, 58, 126, 173	positive	$N = \frac{L}{A}$ *N= natural and seminatural areas* *L= surface of Land use/Land cover classes related to natural and seminatural areas in the selected area* *A= total surface of the selected area*	%	sub-district
	x			x	59	**Green urban spaces**	Natural/green spaces	Lot area occupied by green urban spaces compared to the resident population whithin a selected area	6	30, 37, 48, 126, 149, 173	positive	$N = \frac{G}{P}$ *N= green urban spaces* *G=surface of green urban spaces in the selected area* *P= total population in the selected area*	m^2/inh.	sub-district
x	x				60	**Imperviousness**	Natural/green spaces	Proportion of impermeable surfaces that prevents the infiltration of water into the ground, over the total area	4	36,44,149, 178	negative	$N = \frac{I}{A}$ *N = imperviousness* *I=impermeable areas* *A= total surface of the selected area*	%	sub-district
	x				61	**NDVI**	Natural/green spaces	Normalized difference vegetation Index. It provides informations on the presence and condition of vegetation on the Earth's surface	3	100, 177, 182	positive	$N = \frac{NIR - Red}{NIR + Red}$ *N= Normalized Difference Vegetation Index, where Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively*	adimensional	sub-district
	x			x	62	**Protected areas**	Natural/green spaces	Proportion of Protected areas sourface over the total area	1	30	positive	$N = \frac{P}{A}$ *N= protected areas* *P= surface of the protected areas* *A= total surface of the selected area*	%	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x	x				63	**Public Urban Trees**	Natural/green spaces	The ratio of publicly managed urban trees to the total population in the selected area	1	120	positive	$N = \frac{T}{P}$ *N= public urban trees* *T= number of public urban trees* *P= population in the selected area*	unit/100 inh.	sub-district
	x				64	**Tree cover**	Natural/green spaces	Proportion of ground area covered by the canopy of trees	2	9, 173	positive	$N = \frac{C}{A}$ *N= tree cover density* *C= area covered by tree canopies* *A= total surface of the selected area*	%	sub-district
	x			x	65	**Wetland areas**	Natural/green spaces	Proportion of wetland areas over the total area	2	28, 214	positive	$N = \frac{W}{A}$ *N= wetland area ratio* *W = surface of wetland* *A= total surface of the selected area*	%	district
				x	66	**Plans and Strategies for CCA & DRR**	Planning and programming	Disaster management /Resilience/CCA plans or strategies	2	36, 126	positive	$N = X$ *N= plans and strategues for CCA & DDR* *P= number of plans or strategies in the selected area*	count	urban
			x	x	67	**Investment in prevention, mitigation, answer systems**	Planning and programming	Proportion of investment in geohazard prevention and control, innovtive technologies for risk assessment, mitigation systems... Relative to GDP	2	126, 214	positive	$N = I/GDP$ *N= investment in geohazard* *I= investments in hazard prevention, innovative technologies for risk assessment and mitigation systems* *GDP= Gross Domestic Product*	%	regional
	x				68	**Air pollution**	Pollution	Number of days with concentrations above the local norm or standard for key criteria pollutants (NH_3, NOx, PM 2.5, PM 10, SO_x) in a selected area.	9	11, 30, 37, 48, 64, 97, 149, 152, 214	negative	$N = J$ *N= air pollution* *J = number of days with concentrations above the local norm or standard for key criterion pollutants*	days	district
	x				69	**Noise pollution**	Pollution	Level of noise above EU standards: Lden>=55dB, Lnight>=50dB in a selected area	2	86, 182	negative	$N = K$ *N= noise pollution* *K= level of noise above EU standards*	dB	sub-district
	x				70	**Water pollution**	Pollution	Number of days exceeding Enviromental Quality Standards (water) in a selected area	1	126	negative	$N = K$ *N= water pollution* *K= number of days exceeding Enviromental Quality Standards in the last year*	days	district
x	x				71	**Energy consumption**	Resources / Resources consumption	Total consumption of natural gas and electricity from distribution networks in a selected area	14	30, 36, 48, 64, 97, 120, 131, 149, 152, 100, 187, 214, 100	negativo	$N = \frac{E}{P}$ *N = energy consumption* *E = energy consumption of the community in the selected area in a year* *P = total population in the selected area*	toe*100 inh.	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x	x			72	**Local Agricultural Production Area**	Resources / Resources consumption	Proportion of land used for food production within a selected area.	4	21, 30, 131, 214	positive	$N = \frac{F}{R}$ *N = local agricultural production area* *F = area used for food production* *A= total surface of the selected area*	%	district
x	x				73	**Renewable energy**	Resources / Resources consumption	Propoprtion of energy derived from renewable sources as part of the total gross energy consumption in a selected area	2	36, 149	positive	$N = \frac{R}{E}$ *N = renewable energy* *E = energy consumption of the community in the selected area in a year (expressed in kWh) that comes from renewable sources* E_c *= energy consumption of the community in the selected area in a year*	%	district
x	x				74	**Water consumption**	Resources / Resources consumption	Total amount of water consumed by both the resident population and non-residents in a selected area during a year	12	30,36,48,62,100,120, 121, 131, 173, 187, 214, 215	negative	$N = \frac{K}{P}$ *N= water consumption* *K = total amount of water consumed* *P= total population in the selected area*	l/inh.*year	district
	x	x			75	**Accessibility to green urban spaces**	Services	Percentage of population with access to a green urban area less than 300m away	2	30, 185	positive	$N = \frac{G}{P}$ *N= accessibility to green urban spaces* *G= number of inhabitants living less than 300 m from green areas* *P= total population in the selected area*	%	sub-district
				x	76	**Beds in health institutions**	Services	Number of beds in various medical and health institutions compared to the resident population whithin a selected area.	8	36, 62, 86, 100, 103, 131, 177, 191	positive	$N = \frac{B}{P}$ *N= beds in health institutions* *B = number of bed in health centers and in health insititution* *P= total population in the selected area*	unit/inh.	urban
	x	x			77	**Equipped recreational area**	Services	Total area dedicated to equipped recreational and sports facilities, regardless of whether they are located within green spaces or urban settings, available for the population in a selected area.	1	120	positive	$N = \frac{E}{P}$ *N= equipped recreational area* A_r *= sum of all equipped facility areas* *R = total population in the selected area*	m^2/inh.	sub-district
				x	78	**General practitioners**	Services	Number of general practitioners compared to the resident population whithin a selected area	7	11, 37, 48, 100, 131, 152, 179	positive	$N = \frac{D}{P}$ *N= general practitioners* *D=number of doctors* *P= total population in the selected area*	unit/10,000 inh.	urban
x				x	79	**Hospitals and health centers**	Services	Lot area occupied by hospitals and health centers relative to the number of inhabitants whithin a selected area	3	11, 173, 187	positive	$N = \frac{H}{A}$ *N = hospital and health centers* *H =lot area occupied by hospital and health centers* *A = total population in the selected area*	m^2/inh.	district
x		x	x		80	**Market Area**	Services	Lot area occupied by markets compared to the resident population whithin a selected area	1	120	positive	$N = \frac{M}{R}$ *N = market area* *M= lot area occupie dby markets* *R = total population in the selected area*	m^2/inh.	district

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x	x				81	**Proximity Index**	Services	Proximity and accessibility to basic services, such as food supply, education, health, sport or cultural facilities	1	31	threshold value	$N = PI = \frac{S}{P}$ *N= proximity Index expressed as a percentage* *S= inhabitants near basic services* *R= total population in the selected area*	%	sub-district
x		x		x	82	**Proximity to hospitals**	Services	The estimated time required to reach the nearest hospital or health institution from the selected area.	1	126	negative	$N = T$ *N = proximity to hospitals* *T = time needed to reach the nearest hospital*	s	sub-district
x		x			83	**Public and Affiliated Educational facilities**	Services	Lot area occupied by public educational facilities (such as schools, colleges, and universities) relative to the number of inhabitants in a selected area	5	58, 97, 120, 179, 214	positive	$N = \frac{E}{P}$ *N = public and affiliated educational facilities* *E =lot area occupied by educational facilities* *P= total population in the selected area*	m^2/inh.	sub-district
x		x			84	**Public libraries**	Services	Lot area occupied by public libraries relative to the number of inhabitants in a selected area	1	58	positive	$N = \frac{L}{R}$ *N = public libraries* *L = lot area occupied by public libraries* *R= total population in the selected area*	m^2/inh.	sub-district
x		x			85	**Public or affiliated sports facilities**	Services	Lot area occupied by sport facilities relative to the number of inhabitants in a selected area	1	120	positive	$N = \frac{S}{P}$ *N = public or affiliated sport services* *S = lot area occupied by sport services* *P= total population in the selected area*	m^2/inh.	sub-district
		x	x		86	**Social allowance**	Services	Proportion of population receiving income support from the government for basic needs	3	58, 103, 214	negative	$N = \frac{I}{P}$ *N= social allowance* *I= inhabitants receiving income support for basic needs from government* *P = total population in the selected area*	%	district
		x	x		87	**Social assistance**	Services	Proportion of population receiving social assistance	4	64, 126, 175,179	negative	$N = \frac{S}{P}$ *N= social assistance* *S= inhabitants receiving social assistance* *P= total population in the selected area*	%	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x				x	88	**Brownfield sites**	**Buildings**	Surface and location of unused, abandoned, or underutilized areas, typically previously used for industrial or commercial purposes, which may have potential for redevelopment	added		negative	$N = \frac{B}{A}$ N = *brownfield sites* B= *total area covered by bownfield sites in the selected area* A = *total surface of the selected area*	%	sub-district
x				x	89	**Renovation of public buildings**	**Buildings**	Number and location of renovation interventions (e.g. energy efficiency upgrades ...) of public buildings	added		positive	$N = K$ N= *renovation of public buildings* K= *number of interventions in the selecte area*	count	district
		x		x	90	**Collaboration pacts**	**Collaboration**	Number and location of collaborative agreements with citizens for the shared management of buildings, schools, and public spaces	added		positive	$N = K$ N= *collaboration pacts* K= *number of collaboration pacts in the selected area*	count	district
		x			91	**Aging index**	**Demography**	The number of the elderly aged 65 years and over, per 100 individuals younger than 14 years old in the specific population of a selected area	*added*		threshold value (100)	$N = \frac{A}{P}$ N = *age dependency ratio* A= *number of younger than 15 and older than 64* P= *total population in the selected area*	count	district
x		x		x	92	**Beds in Affiliated student housing**	**Demography**	Total number of available beds in student housing that is provided through agreements between educational institutions and housing providers (affiliated or subsidized housing)	added		positive	$N = \frac{H}{R}$ N = *number of beds in affiliated student housing* H =*number of beds in affiliated student housing* P= *global surface of the selected area*	%	sub-district
		x			93	**NEET**	**Demography**	Proportion of Not in Education, Employment or Training (NEET) individuals on whithin the population of a selected area	added		negative	$N = \frac{N}{P}$ N = *NEET* N_i =*number of NEET individuals* P= *population of the same age group*	%	district
	x				94	**Crop Pollination (Pollinator Abundance)**	**Ecosystem services**	Ecosystem Service of regulation and provisioning that is fundamental for the productivity of many crops. Plant fertilization and, consequently, food production partly depend on wild pollinator species.	*added*	216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub- district
	x				95	**Crop production**	**Ecosystem services**	This provisioning ecosystem service (E.S.) is linked to human land use for productive purposes	*added*	216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x				96	**Erosion Mitigation**	**Ecosystem services**	This regulation ecosystem service (E.S.) evaluates the capacity of healthy soils to reduce the removal of the topsoil layer (rich in organic matter) caused by surface runoff and rainfall	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x				97	**Nutrient Retention**	**Ecosystem services**	This regulation ecosystem service is provided by aquatic and terrestrial ecosystems that filter and decompose organic waste entering inland waters, coastal, and marine ecosystems, supporting potable water supply	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x				98	**Wood production**	**Ecosystem services**	This provisioning ecosystem service (E.S.) is directly tied to soil quality and the market demand for goods	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
	x				99	**Disaster defensive infrastructure**	**Emergency**	Number of facilities, systems, or measures that can be utilized for managing emergencies to withstand and respond to natural disasters (such as floods, hurricanes, wildfires, or hearthquakes)	*added*		positive	$N = \frac{D}{A}$ *N= disaster defensive infrastructure* *D = number of disaster defensive instrastructures referring to facilities, systems, or measures that can be utilized for managing emergencies* *A = surface of high risk areas*	unit/m^2	district
	x	x		x	100	**Preservation of memory**	**Heritage**	The sum of indicators that testify the presence of documents and initiatives that preserve the memory of a disaster, such as: photographic or written archives, associations that preserve the memory of the event, cartographies or maps, community memory, traces of past measures	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing disaster memory preservation* *x = Binary variables (1 if present, 0 if no representing key elements that reflect th preservation of disaster memory* *n= total number of theelements consider*	count	district
		x	x	x	101	**Integrated Strategies for Heritage Protection, Promotion, and Innovation**	**Heritage**	The sum of indicators that testify the presence of: local incentives, community involvement and participation in the legislative process, digitalization and remote systems for assets, and a heritage digitization database	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing the presence of integrated strategies for heritage conservation, promotion and innovation* *x = binary variables (1 if present, 0 if not) representing key elements that reflect the presence of integrated strategies for heritage conservation, promotion and innovation* *n= total number of the elements considered*	count	district
x		x	x		102	**Preservation of good practices and control of heritage**	**Heritage**	The sum of indicators that testify the presence of: best practices for conservation of landscape, territory or heritage, associations that implement these practices, cartographies or maps illustrating their application, local regulations/law supporting conservation and safeguarding actions, monitoring and alert systems	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing the presence of good practices and control of heritage* *x = binary variables (1 if present, 0 if not) representing key elements that reflect the presence of good practices and control of heritage* *n= total number of the elements considered*	count	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x				103	Land capability	Land use	Land-use capability makes it possible to differentiate soils according to their productive potential in the agro-silvopastoral sphere. There are eight classes that define the capacity of soil use and they are divided into two main groupings. Classes 1, 2, 3 and 4 concern soils suitable for cultivation and other uses	*added*		to be defined	$N = \frac{K}{A}$ *N= land capability* *K= surface included in Land Capability Calsses 1 and 2 in the selected area* *A = total surface of the selected area*	%	sub-district
x	x				104	Land take	Land use	Total land take area, which can be expressed as an absolute measure or a relative measure, with respect to the selected area	*added*	221	negative	$N = \frac{K}{A}$ *N= land take* *K= total land take area in the selected area* *A = total surface of the selected area*	%	sub-district
x	x			x	105	Urban transformation zones	Land use	Surface and location of specific areas designated for redevelopment, regeneration, or significant changes in land use	*added*		to be defined	$N = \frac{K}{A}$ *N= urban transformation zones* *K= surface included in Urban transformation zones in the selected area* *A = total surface of the selected area*	%	sub-district
	x				106	Ecological functionality	Natural/green spaces	Amount of areas with High and Moderate Ecological Functionality, according to ecological network analysis (e.g. obtained with ENEA methodology)	*added*	218	positive	$N = \frac{K}{A}$ *N= ecological functionality* *K= surface included in the High and Moderate Ecological Functionality in the selected area* *A = total surface of the selected area*	%	sub-district
	x				107	Elements of the ecological network	Natural/green spaces	Amount of areas of ecological value, according to ecological network analysis (e.g. obtained with ARPA Piemonte methodology - DGR n. 52-1979 del 31/7/2015)	*added*	219	positive	$N = \frac{K}{A}$ *N= elements of the ecological network* *K= Surface included within Areas of ecological Value in the selected area* *A = total surface of the selected area*	%	sub-district
x	x				108	Reused water	Resources / Resources consumption	Proportion of reused water as part of the total gross water consumption in a selected area	*added*		positive	$N = \frac{R}{W}$ *N = re-used water* *R= water consumption of the community in the selected area in a year, that comes from re-used water* *W = water consumption of the community in the selected area in a year*	%	urban

3.3 Considerations

While the initial set of indicators derived from the literature database provides a valuable foundation, its focus on Scopus-indexed literature limits its ability to capture the unique features of a particular place. Resilience is inherently place-based and site specific.

Therefore, the current indicator distribution suffers from an imbalance. Key aspects like heritage and culture, crucial for a territory's resilience, are significantly underrepresented.

For a more comprehensive evaluation, this catalogue should be expanded to include diverse sources beyond Scopus, including grey literature, institutional documents, publications from relevant non-indexed journals, findings from previous research projects in the area, and local databases.

Beyond selecting the indicators themselves, a crucial step involves comparing them to data availability and reference scale. This ensures they align with the specific application and intended policy objectives.

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Appendix A – Literature review database

ID	AUTHORS	TITLE	ABSTRACT	YEAR	DOI	LINK	KEYWORDS	INDICATORS (Y/N)	FORMULA (explicit) (Y/N)	MAP (Y/N)	TIMESCALE	RESILIENCE PHASE/ABILITY	SPATIAL SCALE	SPATIALIZATION METHOD	RESILIENCE DIMENSIONS	RESILIENCE CAPACITIES
4	Feng X.; Xiu C.; Bai L.; Zhong Y.; Wei Y.	Comprehensive evaluation of urban resilience based on the perspective of landscape pattern: A case study of Shenyang city	Urban resilience is a new path for the sustainable development of cities in the future. However, recognizing and quantifying urban resilience is still in the conceptual and exploratory stage. In this study, we present a "scale-density-morphology" resilience framework as well as an index model to investigate the evolution of urban resilience based on theories of landscape ecology and evolutionary resilience. We find that spatial development is a major factor affecting scale resilience; population distribution is significantly related to density resilience; urban growth boundaries and ecological infrastructure are factors for optimizing morphology resilience; and an excellent balance of "scale-density-morphology" fosters the development of resilient urban areas. We give large cities recommendations for developing resilience, including—preventing urban sprawl and controlling the scale of construction land, reducing population and building density to promote low-carbon green production and lifestyles, strengthening ecological networks, and controlling urban growth boundaries, etc. This study hopes to provide a scientifically based spatial guide that could implement resilient urban planning and could serve as a case study for quantitative research on urban resilience. © 2020 Elsevier Ltd	2020	10.1016/j.cities.2020.102722	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85085044159&doi=10.1016%2fj.cities.2020.102722&partnerID=40&md5=6a884cb032dac489491d46e384b445b5	Comprehensive evaluation; Geo-detector; Scale-density-morphology; Shenyang city; Urban resilience		Y	Y	variation over time	N.A.	city	unit-pixel		Diversity, Connectivity, Redundancy, Robustness, Modularity, Adaptability, Multifunctionality, Efficiency
9	Bayulken B.; Huisingh D.; Fisher P.M.J.	How are nature based solutions helping in the greening of cities in the context of crises such as climate change and pandemics? A comprehensive review	Urban areas are expanding due to rural-urban migration and due to population increases. Their resilience is being challenged due to socio-political consequences of increasingly frequent and severe storms, due to climate changes, influx of human and animal refugees and as a consequence of the COVID-19 pandemic. The authors prepared a systematic literature of ways cities can be transformed into more resilient, and sustainable regions by creatively enhancing the quality and quantity of blue and green areas in and around them. The literature review was conducted to provide holistic insights into selection, implementation monitoring, assessment, and valuation of Nature-based Solutions in diverse urban regions. The authors reviewed no fewer than 298 articles from 109 academic journals and related sources, published within 1997–2020. The focus of the articles was upon 'nature-based' changes that are being implemented in urban areas, globally to enhance their resilience and the 'quality-of-life' of humans and other species. By implementing nature-based solutions, and complimentary 'urban wilding' approaches, urban areas and their hinterlands are expanding their 'blue' and 'green' areas and are thereby decreasing the 'heat-island' effects, while improving human health by surrounding them with rich bio-diversities of locally adapted, aquatic and terrestrial plants and animals. Although, many NBS options have been documented to be beneficial, their environmental, economic and social/psychological dimensions have not been adequately quantified, especially in the context of climate changes, and with regard to COVID-19. It is essential that the benefits of NBS are quantified with easily measurable outcomes, that are readily understood by practitioners, city policy-makers and members of community organizations, based upon specific geographical and climatological contexts. This will help them accelerate implementation of NBS and wilding into their urban systems. The reviewers found that more research is needed on anticipatory learning, backcasting and community participation to help to effectively implement the appropriate NBS for improving the sustainability of urban systems. The reviewers provide guidance for urban leaders to incorporate NBS into their policies and strategies to improve urban resilience and equity and to more effectively reduce impacts of climate change, population growth and pandemics. © 2020 Elsevier Ltd	2021	10.1016/j.jclepro.2020.125569	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85098627562&doi=10.1016%2fj.jclepro.2020.125569&partnerID=40&md5=d910da9470843bbf19df36dae3ccd0eb	Air quality; Anticipatory learning; Bio-assessment; Enhanced urban resilience; Heat-island effects; Nature-based solutions; Pandemics; Rewilding; Transformative capacity; Urban sustainability indicators; Urban wellbeing	Y	N	N	current state	N.A.	city	administrative boundary	N.A.	Diversity, Modularity, Tightness of feedbacks, Social Cohesion, Innovation
11	Zhao R.; Fang C.; Liu J.; Zhang L.	The evaluation and obstacle analysis of urban resilience from the multidimensional perspective in Chinese cities	Evaluation of urban resilience is essential for ensuring the health and security of cities in China. This paper describes creating a multi-dimensional index system that evaluates urban resilience across economic, social, institutional, ecological, and infrastructure dimensions. The results show that the urban resilience in China slowly increased over the study period and tended to be balanced across the dimensions, although urban environmental resilience and institutional resilience were generally higher, and economic, social and infrastructure resilience were lower. The spatial heterogeneity of urban resilience was significant, and resilience in eastern China was greater than in the central or western regions of the country. The degree of urban resilience corresponded to city size: larger cities showed more resilience than smaller cities. Analysis of factors that were obstacles to resilience showed that these factors changed dynamically from being factors of infrastructure–economy dimensions to factors of society–institution–ecology dimensions. Carrying out the multi-dimensional evaluation of China's urban resilience can identify the weaknesses of resilience in different dimensions, and to enable the factual decision-making and resource allocation of resilient cities at national and sub-dimensional levels. © 2022	2022	10.1016/j.scs.2022.104160	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85137170176&doi=10.1016%2fj.scs.2022.104160&partnerID=40&md5=1c776393a530fc8aa460fcaec773726a	China; Comprehensive evaluation; Multidimension; Obstacle factor; Urban resilience	Y	N	Y	variation over time	pre-disaster preparedness; resistance; post-disaster recovery capacity	city	administrative boundary	economy, society, institution, ecology, infrastructure	Multifunctionality, Redundancy and modularization, diversity, Multi-scale Networks and connectivity;adaptability
21	Fu X.; Hopton M.E.; Wang X.	Assessment of green infrastructure performance through an urban resilience lens	Green infrastructure (GI) is widely recognized for reducing risk of flooding, improving water quality, and harvesting stormwater for potential future use. GI can be an important part of a strategy used in urban planning to enhance sustainable development and urban resilience. However, existing literature lacks a comprehensive assessment framework to evaluate GI performance in terms of promoting ecosystem functions and services for social-ecological system resilience. We propose a robust indicator set consisting of quantitative and qualitative measurements for a scenario-based planning support system to assess the capacity of urban resilience. Green Infrastructure in Urban Resilience Planning Support System (GIUR-PSS) supports decision-making for GI planning through scenario comparisons with the urban resilience capacity index. To demonstrate GIUR-PSS, we developed five scenarios for the Congress Run sub-watershed (Mill Creek watershed, Ohio, USA) to test common types of GI (rain barrels, rain gardens, detention basins, porous pavement, and open space). Results show the open space scenario achieves the overall highest performance (GI Urban Resilience Index = 4.27/5). To implement the open space scenario in our urban demonstration site, suitable vacant lots could be converted to greenspace (e.g., forest, detention basins, and low-impact recreation areas). GIUR-PSS is easy to replicate, customize, and apply to cities of different sizes to assess environmental, economic, and social benefits provided by different types of GI installations. © 2020	2021	10.1016/j.jclepro.2020.125146	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096862183&doi=10.1016%2fj.jclepro.2020.125146&partnerID=40&md5=2c1fe84ea7a0402d84feee7d81f106f6	Assessment; Green infrastructure; Planning support system; Stormwater management; Urban resilience	Y	Y	N	scenario	absorption; mitigation; adaptation	N.A.	N.A.	Enviromental, Economic, Social	N.A.
28	Wang S.; Palazzo E.	Sponge City and social equity: Impact assessment of urban stormwater management in Baicheng City, China	Cities around the world vulnerable to floods have developed new approaches to urban stormwater management with the aim to increase urban resilience. However, flood risk responses often overlook a broader concept of "resilience" able to address environmental equity issues, including the recognition and participation of communities in urban planning processes. To bridge the gap, this research aims at increasing understanding about the social effects produced by stormwater management projects by assessing how Sponge City programs in China perform from a social equity perspective. Building on a tripartite framework which includes the equitable access to services and opportunities, the acknowledgement of minorities and vulnerable groups and the equitable participation in decision-making processes (distributional, recognitional, and procedural equity), this paper develops an assessment methodology and related indicators that are customized to the Sponge City program. This tripartite framework adapted to the Chinese context also suggests a roadmap for achieving social equity objectives in future urban development initiatives. The results show that the Sponge City program in Baicheng has enhanced distributional equity significantly. However, recognitional equity and procedural equity still need to be improved, and mechanisms to support public participation enhanced. © 2021 Elsevier B.V.	2021	10.1016/j.uclim.2021.100829	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85104079794&doi=10.1016%2fj.uclim.2021.100829&partnerID=40&md5=b5c2822fa8d832740933f2dc88bd2ec7	China; Indicators assessment; Multi-criteria approach; Social equity; Sponge City; Stormwater management	Y	N	N	N.A.	N.A.	city	N.A.	N.A.	N.A.

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30	Delgado-Ramos G.C.; Guibrunet L.	Assessing the ecological dimension of urban resilience and sustainability	We propose a framework for a package of Urban Sustainability and Resilience Indicators (USRI) based on a holistic approach to urban dynamics that we name the 'pyramid of urban resilience and sustainability'. We start with a concise discussion of the concepts of urban resilience and sustainability, their synergies and trade-offs. We then make a point of the need for an interdisciplinary and holistic approach to assess progress towards or away from urban sustainability and resilience; and delineate an analytical framework that enables a comprehensive approach to 'the urban' by addressing not only ecological but also economic, sociocultural and governance dimensions. We critically reflect on its potential (and limits) by applying it to the case of Mexico City. The paper presents preliminary results for the ecological dimension of such a framework, and insights from the case of solid waste. USRI offers the potential for a systemic approach to urban sustainability and resilience. Yet, some limitations are evident, mostly related to data availability at the urban level, complexity to aggregate and weight data, the limited efforts for knowledge coproduction and the incorporation of participatory processes, and the need to cautiously translate findings–and their inherent uncertainties–into decision-making. © 2017 Informa UK Limited, trading as Taylor & Francis Group.	2017	10.1080/19463138.2017.1341890	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85021132646&doi=10.1080%2f19463138.2017.1341890&partnerID=40&md5=03e5c84edd73bd900055a476b5ca4556	Mexico City; urban indicators; urban planning; urban resilience; Urban sustainability	Y	N	N	current state	N.A.	city	N.A.	Ecological	N.A.
31	Tumini I.; Villagra-Islas P.; Herrmann-Lunecke G.	Evaluating reconstruction effects on urban resilience: a comparison between two Chilean tsunami-prone cities	Facing natural disasters is a priority challenge for cities, exacerbated by increases in urban population and climate change. Improving the resilience of cities is a critical need for the international community and especially for territories exposed to multiple risks, such as Chile. Although disasters are always tragic, the recovery and reconstruction post-disaster may provide a unique opportunity to prevent future suffering, enhancing the resilience of local communities. This paper presents the analysis of two Chilean reconstruction programmes applied in Mehuin and Dichato, after the earthquake and tsunami of 22 May 1960 and 27 February 2010, respectively. In both cases, reconstruction programmes were supported by the Chilean Government, but using different approaches: one focused on providing housing for people injured in the earthquake, while the other also included urban amenities and services. This article proposes an urban morphology analysis framework; in addition, it presents the assessment of the two case studies before and after a disaster, thus evaluating their resilience. By comparing urban morphology resilience pre- and post-disaster, a discussion about the effectiveness of two reconstruction approaches is presented. Finally, conclusions and recommendations to better integrate resilience into urban planning are proposed, with the aim of opening the discussion about how to make cities more resilient to natural disasters. © 2016, Springer Science+Business Media Dordrecht.	2017	10.1007/s11069-016-2630-4	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84992364793&doi=10.1007%2fs11069-016-2630-4&partnerID=40&md5=0ce538ca39a4884600df50077a11ed89	Earthquake; Post-disaster reconstruction; Tsunami; Urban morphology indicators; Urban resilience	Y	Y	N	pre-disaster, post-disaster	N.A.	city	N.A.	N.A.	N.A.
36	Fu X.; Wang X.	Developing an integrative urban resilience capacity index for plan making	Urban resilience assessment can help planners understand the status of resilience in an urban system and identify needs for improving resilience capacities. The issues related to urban resilience are complex because of multiple urban system components, threats from different sources, and uncertainty of the future. Urban resilience theories have progressed to consider an urban system as an integrated complex system; however, urban resilience assessments are inconsistent and underdeveloped in assessing an integrated urban system for different threats at various uncertainties. In an effort to address this deficiency, we propose to develop an Integrative Urban Resilience Capacity Index (IURCI) for assessing urban resilience capacity for all threats. To improve the quality of urban resilience assessment, the IURCI considers urban physical form, spatial structure, preparation for future, and performance after plan implementation to measure resilience capacities of absorption, mitigation, and adaptation. It is built in a Scenario-Based Planning Support System (SB-PSS). The SB-PSS is a framework and an open system that integrates IURCI with scenario generation, modeling, and assessment to inform the public, planners, and other stakeholders about the consequences of different planning policies and to assist them make decisions for implementing a preferred scenario. © 2018, Springer Science+Business Media, LLC, part of Springer Nature.	2018	10.1007/s10669-018-9693-6	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85048116802&doi=10.1007%2fs10669-018-9693-6&partnerID=40&md5=ac1af0261ea37ec79621e05fd6b338dc	Capacity assessment; Indicator; Integration; Social-ecological system; Urban resilience	Y	N	N	scenario	absorption; mitigation; adaptation	N.A.	N.A.	Ecological-physical conditions; Economic conditions; Institutional service; Social Capacity	N.A.
37	Lin Y.; Peng C.; Chen P.; Zhang M.	Conflict or synergy? Analysis of economic-social- infrastructure-ecological resilience and their coupling coordination in the Yangtze River economic Belt, China	Urban resilience is a highly integrated system with multiple dimensions involving dynamic transformations and interactions across dimensions. It is crucial for urban sustainability to investigate the coupling coordination relationships between urban resilience subsystems. We used data from 126 cities in 2008, 2012, and 2017 in the Yangtze River Economic Belt (YREB) in China, the entropy weight-TOPSIS method, and a coupling coordination degree (CCD) model to quantify the economic, social, infrastructure, and ecological resilience and the coupling coordination relationships. The results indicated that the economic resilience (EnR), infrastructure resilience (IR), and ecological resilience (EIR) indices exhibited a non-steady increasing trend, whereas the social resilience (SR) index gradually decreased over time. Spatially, the EnR and SR indices decreased from the eastern to the central and western cities, and the IR and EIR indices had high values in the east and west and low values in the midstream region. Interestingly, the midstream region was the only one showing a dramatic decline in the SR and EIR indices, whereas the upstream and downstream areas maintained a steady growth trend for all four indices. Further, the YREB was dominated by cities with high IR and EIR indices, showing a gradual decline in the number of resilience patterns. Combined with the overall and pair-wise coupling coordination results, our findings indicate that the four subsystems were in moderate imbalance. The upstream and midstream regions remained in moderate imbalance, but the downstream regions changed from moderate imbalance to low coordination. Moreover, the interactions of EnR-IR, EnR-EIR, and IR-EIR changed from moderate imbalance to low coordination, and the other pairs of subsystems remained in moderate coordination. This paper sheds new light on the internal mechanism of urban resilience and provides references for practical interventions and policymaking for sustainable urban development. © 2022	2022	10.1016/j.ecolind.2022.109194	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85134887683&doi=10.1016%2fj.ecolind.2022.109194&partnerID=40&md5=e2a14c3844eb2088a217a97f2b045569	CCD model; Coupling coordination relationship; Entropy weight-TOPSIS method; Evaluation; Subsystem resilience; Urban resilience; Yangtze River Economic Belt	Y	N	Y	variation over time	N.A.	city	administrative boundary	economic, social, infrastructure, and ecological resilience	N.A.
38	Shi C.; Guo N.; Gao X.; Wu F.	How carbon emission reduction is going to affect urban resilience	In tackling climate change and promoting sustainable development, carbon emission reduction through means of cleaner production, circular economy and eco-innovation, etc., may lead to increased resilience of an urban system. This study aims to explore the impact of carbon emission reduction on urban resilience and its spatial-temporal characteristics with a sample of 267 prefectural-level cities from 2006 to 2019 in China. Firstly, this research conceptualizes urban resilience as economic prosperity, social wellbeing, cleaner environment and analyzes the impact mechanism of carbon emission reduction on these three dimensions. Then in the empirical analysis, the urban resilience assessment index is built to quantitatively evaluate urban resilience in Chinese cities and its spatial-temporal characteristics. Subsequently, the impact of carbon emission on urban resilience is investigated through geostatistical analysis. The results show that the urban resilience level in China shows significant spatiotemporal heterogeneity. High resilience cities are clustered in the Beijing-Tianjin-Hebei region, Yangtze River Delta region and Pearl River Delta region, while lower resilience cities are in the northeast, northwest and southwest regions. Moreover, urban resilience in Chinese cities is mainly contributed by the economic subsystem. Over the study period, carbon emission reduction is positively related to urban resilience with high resilience and high carbon emission reduction agglomerated over space. Furthermore, the agglomeration effect increased from 2006 to 2019. These indicate that in the past fifteen years, urban resilience in Chinese cities is highly dependent on regional economic development which is still reliant on emission-intensive industries. The research provides important references for China's carbon emission reduction and resilience-building policies. Spatial heterogeneities need to be acknowledged to focus on key areas of emission reduction and resilience improvement in policymaking and implementation. © 2022 Elsevier Ltd	2022	10.1016/j.jclepro.2022.133737	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85136554804&doi=10.1016%2fj.jclepro.2022.133737&partnerID=40&md5=447513b9dc5619a3c9dbbfd1e9ef8925	Carbon emission reduction; China; Climate change; Resilience assessment; Resilient city; Spatial autocorrelation	Y	N	Y	variation over time	N.A.	city	administrative boundary	Economy, society, Environment	N.A.

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44	Wang J.; Foley K.	Assessing the performance of urban open space for achieving sustainable and resilient cities: A pilot study of two urban parks in Dublin, Ireland	The urban environment is at increased risk of unforeseen disturbances associated with climate change and urbanisation. Urban open space, when appropriately located, designed and managed, can potentially support underlying ecosystem services and provide multiple social-ecological benefits. Conversely, poor planning or design can result in mono-functional open space with potentially negative results for the built environment. To anticipate future uncertainty and create more sustainable and resilient cities, it is important to assess the performance of urban open space. This paper provides a deeper understanding of resilience at the scale of open space within the urban fabric and suggests a framework conceptualising resilience with an emphasis on ecosystem services and spatial configuration. A hierarchical index system (HIS) comprising twenty-six measurable indicators and an associated assessment methodology is proposed to evaluate the performance of urban parks in terms of their contribution to urban resilience and sustainability. The applicability of the HIS and assessment methodology is examined in a pilot study by assessing two urban parks in Dublin, Ireland. This paper contributes to the coupling of resilience thinking with urban design by proposing an evaluation method that assists design professionals and urban decision-makers in evaluating the performance of existing schemes and new proposals for urban open space. This paper will help a range of stakeholders better understand the settings of these spaces through scientific evidence. © 2021 The Authors	2021	10.1016/j.ufug.2021.127180	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105827749&doi=10.1016%2fj.ufug.2021.127180&partnerID=40&md5=0a6943c3aa22c5df8eadf20597ab4492	Analytic hierarchy process; Assessment methodology; Conceptual model; Hierarchical index system; Performance indicators	Y	N	N	current state	N.A.	Urban park	N.A.	N.A.	N.A.
48	Lin Y.; Peng C.; Shu J.; Zhai W.; Cheng J.	Spatiotemporal characteristics and influencing factors of urban resilience efficiency in the Yangtze River Economic Belt, China	Urban resilience efficiency is an important indicator to explore the relationship between resource consumption and urban resilience, shedding new light on the study of urban sustainable development. Based on the panel data of 2008, 2012, and 2017, this paper makes a spatiotemporal assessment on the urban resilience efficiency of 126 cities in the Yangtze River Economic Belt (YREB) in China by applying an entropy weight-TOPSIS method and a slack-based measure (SBM) model. Combined with the analysis of a geographically weighted regression model (GWR), the influencing factors on resilience efficiency are also investigated. The results show that both the resource consumption index (RC, inputs) and the urban resilience index (UR, outputs) presented a steady upward trend, and their spatial distribution characteristics were similar, showing a gradual decrease from the eastern coastal cities to the central and western inland cities. Derived from inputs and outputs, the mean values of resilience efficiency index (RE) in three periods were 0.3149, 0.2906, and 0.1625, respectively, revealing that there had been a noticeable decline. Spatially, its spatial distribution has evolved from a relatively balanced pattern to an unbalanced one, showing a gradual decrease from west to east. The results of the GWR model analysis indicate that the total electricity consumption and area of construction land had a considerable correlation with the overall urban resilience of the YREB. Furthermore, total quantity of water supply and science and technology (S&T) expenditure continued to be the main driving factors on urban resilience of the upstream cities. The midstream regions mainly depended on the scale of construction land, and the influencing factors are relatively single. The influencing factors in the downstream areas have changed from dominance of resources and capital factors to the single dominance of resource factors, and total electricity consumption had a strong explanatory power. Based on these findings, we had put forward the overall and local regional policy implications. © 2022, The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature.	2022	10.1007/s11356-021-18235-2	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124157349&doi=10.1007%2fs11356-021-18235-2&partnerID=40&md5=fe2a3bd0b7985d074a77a2d09fb5d725	Entropy weight-TOPSIS method; Evaluation; GWR model; Influencing factors; Resilience efficiency; SBM model; Urban resilience; Yangtze River Economic Belt	Y	N	Y	variation over time	N.A.	city	administrative boundary	Economy, society, infrastructure, ecology	N.A.
57	Barreiro J.; Lopes R.; Ferreira F.; Matos J.S.	Index-based approach to evaluate city resilience in flooding scenarios	Intense rainfall events combined with high tide levels frequently result in urban floods in riverine or coastal cities. Their increasing variability and uncertainty demand urgent but sustained responses. Thus, resilience-driven approaches are emerging in contrast to the traditional technical-economic frameworks, as urban resilience reflects the overall capacity of a city to survive, adapt and thrive when experiencing stresses and shocks. This paper presents a simplified index-based methodology for the evaluation and quantification of urban resilience to flooding, based on the works developed in the EU H2020 RESCCUE project. A set of five indicators are proposed to compute the Integrated Urban Resilience Index (IURI), allowing to classify resilience according to a proposed range of rankings. This methodology considers simultaneously a multisectoral approach, reflecting services interdependences, and a sectorial approach, applying 1D/2D computational modelling of the urban drainage network. It was applied to the study case of Lisbon downtown, involving the analysis of interdependencies between 124 infrastructures of 10 urban services. Two scenarios were considered, respecting the current and future situations, considering climate changes. Results enhance the usefulness, practicability, and potential of the proposed approach, and improvement opportunities were also identified for future developments. © 2021 by the authors. Licensee C.E.J, Tehran, Iran.	2021	10.28991/cej-2021-03091647	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85101812967&doi=10.28991%2fcej-2021-03091647&partnerID=40&md5=11f0772c83c57252ccb10b8735dd5048	1D/2D Drainage Modelling; Cascade Effects; City Resilience; Resilience Assessment; Urban Flooding	Y	Y	N	scenario	N.A.	N.A.	N.A.	N.A.	N.A.
58	Kim D.; Song S.-K.	Measuring changes in urban functional capacity for climate resilience: Perspectives from Korea	The purpose of this study is to measure urban resilience through indicators related to urban function and to classify 232 cities in Korea with regard to climate variability. Urban functions were classified into basic, developmental, sustainable, and maintenance functions, and were measured using 25 indicators. Confirmatory factor analysis was used to integrate each function into a single value. Cluster analysis was applied to 232 cities in Korea and analyzed for the years 2000, 2005, and 2010. The analysis revealed that clusters appeared between variables centered on metropolitan cities and variables of climate variability. In 2000 and 2005, Korean cities had similar clusters, but in 2010, they manifested a different pattern. This study suggests that the construction and accumulation of time-series data is necessary for understanding the lack of each function of the city in constructing adaptation policies for communities. © 2018 Elsevier Ltd	2018	10.1016/j.futures.2018.05.001	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85047356298&doi=10.1016%2fj.futures.2018.05.001&partnerID=40&md5=e08e6eeaea576b0f74e[illegible]	Climate change adaptation; Climate resilience; Resilience indicators; Urban function; Urban resilience	Y	N	Y	variation over time	N.A.	city	administrative boundary	N.A.	N.A.
62	Mu X.; Fang C.; Yang Z.	Spatio-temporal evolution and dynamic simulation of the urban resilience of Beijing-Tianjin-Hebei urban agglomeration	The continuous growth of urban agglomerations in China has increased their complexity as well as vulnerability. In this context, urban resilience is critical for the healthy and sustainable development of urban agglomerations. Focusing on the Beijing-Tianjin-Hebei (BTH) urban agglomeration, this study constructs an urban resilience evaluation system based on four subsystems: economy, society, infrastructure, and ecology. It uses the entropy method to measure the urban resilience of the BTH urban agglomeration from 2000 to 2018. Theil index, standard deviation ellipse, and gray prediction model GM (1,1) methods are used to examine the spatio-temporal evolution and dynamic simulation of urban resilience in this urban agglomeration. Our results show that the comprehensive evaluation index for urban resilience in the BTH urban agglomeration followed a steady upward trend from 2000 to 2018, with an average annual growth rate of 6.72%. There are significant differences in each subsystem's contribution to urban resilience; overall, economic resilience is the main factor affecting urban resilience, with an average annual growth rate of 8.06%. Spatial differences in urban resilience in the BTH urban agglomeration have decreased from 2000 to 2018, showing the typical characteristic of being greater in the central core area and lower in the surrounding non-core areas. The level of urban resilience in the BTH urban agglomeration is forecast to continue increasing over the next ten years. However, there are still considerable differences between the cities. Policy factors will play a positive role in promoting the resilience level. Based on the evaluation results, corresponding policy recommendations are put forward to provide scientific data support and a theoretical basis for the resilience construction of the BTH urban agglomeration. © 2022, Science in China Press.	2022	10.1007/s11442-022-2022-5	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85137048406&doi=10.1007%2fs11442-022-2022-5&partnerID=40&md5=6307dcdadad85d8003f663f1c6112830	Beijing-Tianjin-Hebei (BTH); evaluation system; gray prediction model; urban agglomeration; urban resilience	Y	N	Y	variation over time	N.A.	urban agglomeration	administrative boundary	Urban economic resilience; Urban social resilience; Urban infrastructural resilience; Urban ecological resilience	N.A.

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64	Zhang M.; Yang Y.; Li H.; van Dijk M.P.	Measuring urban resilience to climate change in three chinese cities	Building an urban resilience index results in developing an increasingly popular tool for monitoring progress towards climate-proof cities. This paper develops an urban resilience index in the context of urban China, which helps planners and policy-makers at city level to identify whether urban development is leading to more resilience. The urban resilience index (URI) suggested in this research uses data on 24 indicators distributed over six URI component indices. While no measure of such a complex phenomenon can be perfect, the URI proved to be effective, useful and robust. Our findings show that the URI ensures access to integrated information on urban resilience to climate change. It allows comparisons of cities in a systematic and quantitative way, and enables identification of strong and weak points related to urban resilience. The URI provides tangible measures of not only overall measures of urban resilience to climate change, but also urban resilience components and related indicators. Therefore, it could meet a wide range of policy and research needs. URI is a helpful tool for urban decision-makers and urban planners to quantify goals, measure progress, benchmark performance, and identify priorities for achieving high urban resilience to climate change. © 2020 by the	2020	10.3390/su12229735	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096397059&doi=10.3390%2fsu12229735&partnerID=40&md5=ab1a3c5a8fb45e052cc94be0f8e17c64	Climate change; Hazards management; Resilience assessment; Urban governance; Urban resilience	Y	N	N	variation over time	N.A.	city	N.A.	society, economy, community, ecological environment, infrastructure, institution	N.A.
86	Jiao L.; Wang L.; Lu H.; Fan Y.; Zhang Y.; Wu Y.	An assessment model for urban resilience based on the pressure-state-response framework and BP-GA neural network	It has been widely appreciated that urban resilience is one of the core goals of urban development. Various approaches for evaluating the level of urban resilience have been developed recently. However, previous urban resilience assessment studies have mainly concentrated on the economy, society, infrastructure, and ecological environment, with very few considering the characteristics of the urban resilience regression process. Therefore, this research proposes a new assessment framework for urban resilience from the perspective of "pressure-state-response" to address this issue. And then, the methods of the BP neural network, genetic algorithm, Moran's index and the center of gravity model are combined to establish the assessment model of urban resilience. 31 provinces in Mainland China are selected as a case study to demonstrate the application of the assessment model. The calculation results indicate that the urban resilience level of all provinces in China is rising, and the provincial urban resilience development shows the characteristics of fluctuation. The trend of urban resilience shifted from north to south from 2013 to 2019, consistent with China's economic center of gravity moving from north to south. This study develops a new angle for evaluating urban resilience and provides effective policies toward urban resilience. © 2023	2023	10.1016/j.uclim.2023.101543	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85158066166&doi=10.1016%2fj.uclim.2023.101543&partnerID=40&md5=3b136a6803ad9c895232644995b18198	Assessment model; BP neural network; Framework; Pressure-state-response; Urban resilience	Y	N	Y	variation over time	Pressure; State; Response	province	administrative boundary	N.A.	N.A.
90	Liu Y.; Liu W.; Lin Y.; Zhang X.; Zhou J.; Wei B.; Nie G.; Gross L.	Urban waterlogging resilience assessment and postdisaster recovery monitoring using NPP-VIIRS nighttime light data: A case study of the 'July 20, 2021' heavy rainstorm in Zhengzhou City, China	In recent years, with the acceleration of urbanization and abnormal changes in the overall climate, cities have been increasingly threatened and affected by disasters. Assessing and improving urban resilience, as well as postdisaster recovery monitoring, are of great significance for relevant municipal departments. Taking the heavy rainstorm event that occurred on July 20, 2021, in Zhengzhou City as an example, this study explored the resilience and postdisaster recovery of Zhengzhou City based on remote sensing data and other multisource data. First, we calculated the resilience assessment index and built an assessment model. Then, we analyzed and evaluated the resilience. Finally, based on NPP-VIIRS nighttime light data, we verified the accuracy of the resilience results and dynamically monitored the postdisaster recovery process. The results show that the overall resilience of Zhengzhou City to waterlogging disasters is low in the southwest and high in the northeast. The changing trend of the nighttime light brightness following the disaster was consistent with the resilience assessment results. Then, due to rescue work, the light index increased briefly in July; Due to the serious impact of the disaster, the facilities were damaged, and the light index was reduced in August. With the development of recovery work, the disaster-influenced and light index areas gradually recovered and exceeded the predisaster level. Corresponding urban resilience strategies were proposed based on the assessment results. This study can provide a scientific basis and reference for relevant aspects such as disaster prevention, recovery, and reconstruction in Zhengzhou City and other cities. © 2023 Elsevier Ltd	2023	10.1016/j.ijdrr.2023.103649	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85150490390&doi=10.1016%2fj.ijdrr.2023.103649&partnerID=40&md5=9591e840d8e0daf8eb02f85d5e1c13f7	China; NPP-VIIRS nighttime Lights; Postdisaster recovery monitoring; Resilience assessment; Urban waterlogging; 'July 20' heavy rainstorm in Zhengzhou City	Y	N	Y	current state	N.A.	city	administrative boundary	Social, economic	N.A.
97	Chen X.-L.; Yu L.-X.; Lin W.-D.; Yang F.-Q.; Li Y.-P.; Tao J.; Cheng S.	Urban resilience assessment from the multidimensional perspective using dynamic Bayesian network: A case study of Fujian Province, China	Pursuing the high-quality urbanisation and improving urban system reliability are the current goal of urban development. Urban resilience reflects the reliability of a city in coping with external and internal disturbances. Therefore, the urban system reliability can be quantified by assessing urban resilience. Simultaneously, urban resilience assessments can identify vulnerabilities that affect the urban system reliability. Based on this, targeted decisions are proposed to enhance the reliability, stability and safety of urban systems. This study constructs an assessment indicator system to quantitatively estimate the reliability of urban systems and develops a dynamic urban resilience assessment model by combining it with a dynamic network framework that accounts for time-varying factors. The model estimates the urban system reliability from a resilience perspective and identifies vulnerabilities in urban resilience. The applicability of the model is verified using Fujian Province as a research case. The case study uses annual urban data from 2016 to 2021, which is outstanding in terms of data objectivity. The results provide important insights for practitioners and researchers in optimising urban resilience, improving urban system reliability and formulating urban development strategies. © 2023 Elsevier Ltd	2023	10.1016/j.ress.2023.109469	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85163509029&doi=10.1016%2fj.ress.2023.109469&partnerID=40&md5=951ac197b490515ce1ac5db0880aea1b	Dynamic Bayesian network; Multidimensional perspective; Resilience assessment; Urban resilience	Y	N	N	variation over time	N.A.	province	N.A.	Society; Economy; Ecology; Institution; Infrastructure	N.A.
100	Wang H.; Liu Z.; Zhou Y.	Assessing urban resilience in China from the perspective of socioeconomic and ecological sustainability	Global uncertainties brought about by external shocks have surged in recent years, posing huge challenges to achieve the global 2030 Sustainable Development Goals. Urban resilience determines how cities responds, adapts and recovers from external shocks. At present, the theoretical analysis and systematic evaluation of urban resilience in China are still insufficient. Here, we constructed an urban resilience index (URI) system from the perspective of socioeconomic and ecological sustainability to evaluate the urban resilience of prefecture-level cities in China from 2000 to 2020. Then, entropy method and exploratory spatial data analysis (ESDA) were used to investigate the spatiotemporal evolution of urban resilience in China. Finally, the influencing factors that hinder the improvement of urban resilience in China were identified through the obstacle diagnosis model. Results showed that over the past 20 years, China's urban resilience has been greatly improved, as shown in the average URI increased from 0.048 in 2000 to 0.092 in 2010, and further raised to 0.148 in 2020. But the growth rate of China's urban resilience improvement over the past decade (2010–2020) has been slower than in the previous decade (2000–2010). Over the past two decades, China's urban resilience varied across the geographical regions, urban agglomerations and population scales, showing that URI was higher in eastern regions, urban agglomerations and cities with larger population scales than in the mid-west, non-urban agglomerations, and cities with smaller population scales. China's urban resilience has positive spatial auto-correlation, indicating that cities with higher or lower URI tend to have a trend of spatial agglomeration. The dominant factors that hinder the improvement of urban resilience in China have changed over time, manifested as the role of infrastructure gradually weakening, and the role of economic level, industrial structure, and education level gradually strengthening. In view of the heterogeneity of urban resilience in China and the complexity of its influencing factors, differentiated rather than one-size-fits-all countermeasures to improve urban resilience may be more effective. Our findings would provide a beneficial reference for China and other developing countries to optimize urban planning to cope with external shocks and build sustainable and resilient cities. © 2023 Elsevier Inc.	2023	10.1016/j.eiar.2023.107163	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85161073221&doi=10.1016%2fj.eiar.2023.107163&partnerID=40&md5=bb085da8884524e2c368e67befe622ec	China; Entropy method; ESDA; Resilience assessment; Urban resilience	Y	N	Y	variation over time	N.A.	city	administrative boundary	Economic resilience; Social; Ecological; Infrastructure	N.A.

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ID	AUTHORS	TITLE	ABSTRACT	YEAR	DOI	LINK	KEYWORDS	INDICATORS (Y/N)	FORMULA (explicit) (Y/N)	MAP (Y/N)	TIMESCALE	RESILIENCE PHASE/ABILITY	SPATIAL SCALE	SPATIALIZATION METHOD	RESILIENCE DIMENSIONS	RESILIENCE CAPACITIES
103	Cao F.; Xu X.; Zhang C.; Kong W.	Evaluation of urban flood resilience and its Space-Time Evolution: A case study of Zhejiang Province, China	Urban floods have become increasingly frequent in recent years, highlighting the need for resilience evaluation and the identification of strategies to improve urban flood resilience. In this study, a system of resilience evaluation indicators is proposed to quantitatively evaluate the level of urban flood resilience. The entropy method used to calculate the resilience index and the space–time permutation scan method used to analyze the space–time aggregation characteristics of urban resilience levels are combined to establish a methodology for evaluating urban flood resilience. An evaluation indicator system for urban flood resilience is proposed, encompassing aspects of natural, economy, society, and infrastructure. This system attuned to the local needs of urban flood resilience evaluation, tests the applicability of the Guide for Safety Resilient City Evaluation (GB/T 40947–2021) in this study. Moreover, it incorporates key common indicators extracted from prior studies on urban flood resilience evaluation. Zhejiang Province, a flood-prone area in China, is selected as the study area, and the proposed evaluation indicator system is used to evaluate the urban flood resilience levels in Zhejiang and their space–time trends from 2011 to 2020. The results show that resilience levels have improved in the natural, economic, and infrastructure aspects, while the resilience levels of social aspect remain high. From 2011 to 2014, two distinct aggregation patterns emerged, delineated as inland-type and coastal-type aggregation areas. An analysis of both patterns was conducted, considering an array of influencing indicators, such as green coverage rate in built-up areas, population age structure index, gross domestic product, density of resident population in built-up areas, and per capita disposable income. The period from 2014 to 2020, however, did not reveal any significant aggregation characteristics. This study provides a reference for establishing an urban flood resilience evaluation indicator system and an in-depth understanding of urban flood resilience, and targeted recommendations to bolster urban flood resilience in the study area. © 2023 The Authors	2023	10.1016/j.ecolind.2023.110643	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85166620732&doi=10.1016%2fj.ecolind.2023.110643&partnerID=40&md5=e9d64ecc98182dbd93c851b42110afd0	Evaluation; Flooding; Indicators; Space–time aggregation; Urban resilience	Y	N	Y	variation over time	N.A.	province	administrative boundary	Nature; Economy; Society;Infrastructure	N.A.
120	Salazar-Llano L.; Rosas-Casals M.; Ortego M.I.	An exploratory multivariate statistical analysis to assess urban diversity	Understanding diversity in complex urban systems is fundamental in facing current and future sustainability challenges. In this article, we apply an exploratory multivariate statistical analysis (i.e., Principal Component Analysis (PCA) and Multiple Factor Analysis (MFA)) to an urban system's abstraction of the city's functioning. Specifically, we relate the environmental, economical, and social characters of the city in a multivariate system of indicators by collecting measurements of those variables at the district scale. Statistical methods are applied to reduce the dimensionality of the multivariate dataset, such that, hidden relationships between the districts of the city are exposed. The methodology has been mainly designed to display diversity, being understood as differentiated attributes of the districts in their dimensionally-reduced description, and to measure it with Euclidean distances. Differentiated characters and distinctive functions of districts are identifiable in the exploratory analysis of a case study of Barcelona (Spain). The distances allow for the identification of clustered districts, as well as those that are separated, exemplifying dissimilarity. Moreover, the temporal dependency of the dataset reveals information about the district's differentiation or homogenization trends between 2003 and 2015. © 2019 by the authors.	2019	10.3390/su11143812	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85068905717&doi=10.3390%2fsu11143812&partnerID=40&md5=6adf8c6db391002f95c744072595ada9	Barcelona; Biplot; Multiple Factor Analysis (MFA); Principal Component Analysis (PCA); Sustainability indicators; Urban diversity; Urban resilience; Urban sustainability	Y	N	N	current state	N.A.	city	N.A.	N.A.	N.A.
121	Shaker R.R.; Aversa J.; Papp V.; Serre B.M.; Mackay B.R.	Showcasing relationships between neighborhood design and wellbeing Toronto indicators	Cities are the keystone landscape features for achieving sustainability locally, regionally, and globally. With the increasing impacts of urban expansion eminent, policymakers have encouraged researchers to advance or invent methods for managing coupled human-environmental systems associated with local and regional sustainable development planning. Although progress has been made, there remains no universal instrument for attaining sustainability on neither regional nor local planning scales. Previous sustainable urbanization studies have revealed that landscape configuration metrics can supplement other measures of urbanwell-being, yet few have been included in public data dashboards or contrasted against local well-being indicators. To advance this sector of sustainable development planning, this study had three main intentions: (1) to produce a foundational suite of landscape ecology metrics from the 2007 land cover dataset for the City of Toronto; (2) to visualize and interpret spatial patterns of neighborhood streetscape patch cohesion index (COHESION), Shannon's diversity index (SHDI), and four Wellbeing Toronto indicators across the 140 Toronto neighborhoods; (3) to quantitatively assess the global collinearity and local explanatory power of the well-being and landscape measures showcased in this study. One-hundred-and-thirty landscape ecology metrics were computed: 18 class configuration metrics across seven land cover categories and four landscape diversity metrics. Anselin Moran's I-test was used to illustrate significant spatial patterns of well-being and landscape indicators; Pearson's correlation and conditional autoregressive (CAR) statistics were used to evaluate relationships between them. Spatial "hot-spots" and/or "cold-spots" were found in all streetscape variables. Among other interesting results, Walk Score® was negatively related to both tree canopy and grass/shrub connectedness, signifying its lack of consideration for the quality of ecosystem services and environmental public health-and subsequently happiness-during its proximity assessment of socioeconomic amenities. In sum, landscape ecology metrics can provide cost-effective ecological integrity addendum to existing and future urban resilience, sustainable development, and well-being monitoring programs. © 2020 by the authors.	2020	10.3390/su12030997	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85081220429&doi=10.3390%2fsu12030997&partnerID=40&md5=baa0439daa3579ca53d4434a2cb9505c	Crime; Data dashboard; Landscape indicators; Premature mortality; Spatial autoregressive modeling; Streetscapes; Sustainable urbanization; Toronto; Urban design; Urban landscape; Urban planning; Walk score	Y	N	Y	current state	N.A.	neighbourhood	single elements	Social; landscape	N.A.
126	Gaber R.M.; El-Kader M.Hu.; Okba E.M.	The Resilience Performance Index, a Fuzzy Logic Approach to Assess Urban Resilience	Urban resilience is recently a prominent issue due to rapid urbanization and increasing challenges and stressors affecting cities. Assessment of urban resilience is an essential step in enhancing resilience performance since regular assessment informs resilience action plans, determines areas of deficiencies, and provides spatial and temporal comparisons. However, resilience assessment is a complex process that requires intensive data and resources due to the multi-dimensional and dynamic nature of resilience, and the imprecision of resilience data. In this context, the research aims to develop The Resilience Performance Index (RPI), through setting a conceptual framework, defining relevant resilience indicators, and finally modelling resilience performance using The Fuzzy Logic Approach, aiming to combine resilience analysis with artificial intelligence (AI) tools and dynamic modelling methods. The RPI assesses both qualitative and quantitative resilience indicators obtained through records, census data or structured questionnaires. Indicators' values are modelled through a designed fuzzy logic system to obtain the resilience performance score. The developed index is applied on New Damietta city to inform resilience action plans in the Nile Delta region. The RPI addresses the complexity of resilience assessment and ambiguity of resilience data through an easy applicable, user friendly approach without the need for complex mathematical and statistical methods. © 2022 WITPress. All rights reserved.	2022	10.18280/ijsdp.170421	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85136853033&doi=10.18280%2fijsdp.170421&partnerID=40&md5=dbeda2f39fe7fcc2123fc48de1dffffb	artificial intelligence; assessment; fuzzy logic; resilience indicators; urban resilience	Y	N	N	current state	N.A.	N.A.	N.A.	Natural and environmental; Physical and built environment; Social and economic; Governance and institutional	Robustness; efficiency; Resourcefulness; Redundancy; Adaptation

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130	Wang X.; Wang C.; Shi J.	Evaluation of urban resilience based on Service-Connectivity-Environment (SCE) model: A case study of Jinan city, China	Resilience has become one of the main drivers for planning city future. However, there is currently no universally accepted definition and measurement of urban resilience. This study introduces and demonstrates a Service-Connectivity-Environment (SCE) model to evaluate urban resilience. First, this paper defines urban resilience based on existing research and presents a framework for urban resilience based on service, connectivity, and environment. Second, this study introduces a SCE model used to evaluate urban resilience. This paper presents an indicator system for urban resilience assessment with eight indicators. In contrast to previous urban resilience evaluation systems, the developed evaluation system is two-dimensional. One dimension is service, connectivity, and environment, and the other is basic and coordination. Service mainly refers to urban service facilities, connectivity mainly refers to transportation system, and environment mainly refers to the landscape of green space and water bodies. Third, as an illustrative example, apply the SCE model to Jinan, Shandong Province, China. The study focuses on the temporal and spatial characteristics of urban resilience in Jinan. The analysis provides initial evidence that the level of urban resilience in the SCE dimension of Jinan City varies, and the regional gap gradually increases during the study period. The SCE model provides a general and replicable approach to resilience assessment that can be implemented for a broader range of applications. © 2023	2023	10.1016/j.ijdrr.2023.103828	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85166016313&doi=10.1016%2fj.ijdrr.2023.103828&partnerID=40&md5=ac5802c629e3efcd1d10d18d66441c57	Comprehensive evaluation; Connectivity resilience; Environment resilience; Jinan city; Service resilience; Urban resilience	Y	N	Y	variation over time	N.A.	district	administrative boundary	Service resilience; Connectivity Resilience; Environment Resilience	N.A.
131	Wu P.; Duan Q.; Zhou L.; Wu Q.; Deveci M.	Spatial-temporal evaluation of urban resilience in the Yangtze River Delta from the perspective of the coupling coordination degree	Scientific evaluation of urban resilience will help to improve the ability of self-prevention and self-recovery when facing internal and external pressure. However, existing studies are on basis of the overall perspective of the urban resilience evaluation index system to measure urban resilience, often ignoring the coupling and coordination degree among indicators. Therefore, an empirical analysis is developed, which is used to measure the urban resilience of eight cities in the Yangtze River Delta urban agglomeration from 2010 to 2019 from the perspective of coupling coordination degree based on the urban resilience evaluation index system. The empirical results show that (1) In time, the eight cities' resilience fluctuated dynamically and varied to different degrees. It presents the spatial distribution characteristics of "high in the center and low in the periphery" in space. (2) In time, the coupling coordination degree in the eight cities fluctuated slightly. The spatial distribution pattern of "high in the center and low in the periphery" was formed in terms of space. (3) There is a long-term stable relationship between urban resilience and the coupling coordination degree among all indicators. In a certain sense, the higher the coupling coordination degree is, the higher the urban resilience is. These results can improve urban resilience to some extent and make cities more resilient in the future collaborative development process, and provide a way to evaluate urban resilience at different spatial-temporal scales. © 2023, The Author(s), under exclusive licence to Springer Nature B.V.	2023	10.1007/s10668-023-03087-2	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85149814715&doi=10.1007%2fs10668-023-03087-2&partnerID=40&md5=5186f9d9b0c537fca691573f3a6e0dfb	Coupling coordination degree; Econometric panel model; Spatial-temporal evaluation; Urban resilience; Yangtze River Delta urban agglomerations	Y	N	Y	variation over time	N.A.	city	administrative boundary	Infrastructure, Economic, Ecologic, Social	N.A.
149	Oliveira B.; Fath B.D.	Comparative Resilience Evaluation—Case Study for Six Cities in China, Europe, and the Americas	The historical development of the urban realm has brought marvelous benefits to humankind, which has profited from the infrastructure, services, and social networks provided by cities. Nonetheless, considering current and future risks, understanding how cities can absorb impacts and reorganize their structure while keeping their identities is fundamental and timely. In other words, understanding how to promote resilience is crucial. This study developed a comparative urban resilience index (CURI) formed by 29 indicators and applied it to case studies in Europe, China, and the Americas (Malmö, Vienna, Beijing, Shanghai, Baltimore, and São Paulo). An innovative identity dimension was built to embrace the cultural traits of studied cities. Results point to a systemic property of CURI when comparing cities in both timeframes (2000 and 2020). In addition, two groups were formed: Malmö, Beijing, and Baltimore increased their resilience due to higher performance in at least two dimensions; Shanghai, Vienna, and São Paulo decreased their resilience due to lower performance in at least three dimensions. Ranking the data in terms of the benchmark promoted a quick understanding of which city is the "best in class" for each dimension, creating a clear way forward for other cities to follow. © 2023 by the authors.	2023	10.3390/land12061182	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85163827009&doi=10.3390%2fland12061182&partnerID=40&md5=c5e445945ec46346eb54ffb16707ef19	cities; climate change; indicators; resilience; urban resilience	Y	N	N	variation over time	N.A.	city	N.A.	Population; Economic; Governance; Health; Environment; Identity	N.A.
150	Sharma S.; Kumar S.; Singh A.	Assessment of Green Infrastructure for sustainable urban water management	Green Infrastructure (GI) offers a contemporary approach for mitigating flood risk, improving water quality and managing urban storm water for sustainable use. Green Infrastructure promotes landscape planning in urban resilience to enhance sustainable development. Moreover, the present literature is lacking in ensuring the comprehensive assessment of Green Infrastructure performance in terms of ecosystem function and considering serviceability for social, ecological and economical system resilience. In this study, robust indicator is proposed to set fuzzy comprehensive evaluation (FCE) for quantitative and qualitative analysis for sustainable water management to assess the capacity of urban resilience. Green Infrastructure urban resilience water management system (GIUR-WMS) helps in decision-making for Green Infrastructure planning by comparing scenario generation to ensure urban resilience capacity index. To demonstrate the GIUR-WMS, we develop five alternatives/scenarios in five sectors of Chandigarh (12, 26, 14, 17 and 34) to test common type of GI (rain barrel, rain gardens, detention basins, porous pavements and open spaces). Result shows that the open spaces achieve highest Green Infrastructure urban resilience index of 4.22/5. To implement the open space scenario in urban sites, suitable vacant can be converted to green spaces (for example forest, low impact recreation areas and detention basins); GIUR-WMS is easy to replicate, customize and apply to cities of different sizes to assess environmental, social and ecological dimensions. © 2023, The Author(s), under exclusive licence to Springer Nature B.V.	2023	10.1007/s10668-023-03411-w	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85160840192&doi=10.1007%2fs10668-023-03411-w&partnerID=40&md5=32e63ef4f40b7b127e8236a0b483654d	Assessment; Fuzzy comprehensive evaluation; Green Infrastructure; Urban resilience; Water management system	Y	N	N	scenario	N.A.	city	N.A.	Environmental; Economical; Social	N.A.
152	Zhang J.; Yang X.; Lu D.	Evaluation of Urban Resilience Based on Trio Spaces: An Empirical Study in Northeast China	Realizing the building of urban resilience and improving urban resilience has become important contents of urban development. In view of this phenomenon, relying on the framework of trio spaces, which includes physical space, societal space, and cyberspace, the evaluation index system of urban resilience is established. The evaluation model of urban resilience is constructed by using CRITIC-entropy weight and the cloud evaluation method. Four sub-provincial cities in Northeast China, Harbin, Changchun, Shenyang, and Dalian, are selected as the analysis objects, and the resilience of each city is comprehensively evaluated and spatially evaluated. From the urban resilience comprehensive evaluation, this paper found the cities with the highest resilience levels in 2014, from 2015 to 2018, and from 2019 to 2020 are Dalian, Changchun, and Shenyang, respectively. The city with the lowest resilience level is Harbin. Although there are differences in resilience evaluation values of four cities, the resilience levels of these cities are all "qualified". From the urban resilience sub-space evaluation, this paper explored the shortcomings of the resilience of physical space, societal space, and cyberspace of each city through the comparison. Then, some suggestions about highlighting the enhancement of cyberspace resilience, emphasizing resilience-building balance, conducting resilience evaluation, and monitoring regularly, and local government policy support are proposed to help to promote urban resilience from the concept of trio spaces. © 2023 by the authors.	2023	10.3390/buildings13071695	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85166240229&doi=10.3390%2fbuildings13071695&partnerID=40&md5=206aaf07c266b02de5a0595e5e1634f2	evaluation; Northeast China; trio spaces; urban resilience	Y	N	N	current state	Resistance; Self-Recovery; Learning	N.A.	N.A.	Physical Space; Social Space; Cyber Space	N.A.

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173	Chen J.; Ma H.; Yang S.; Zhou Z.; Huang J.; Chen L.	Assessment of Urban Resilience and Detection of Impact Factors Based on Spatial Autocorrelation Analysis and GeoDetector Model: A Case of Hunan Province	The rapid development of urbanization has led to increasing uncertainties related to urban safety risks, which has brought certain challenges to the sustainable development of cities. The concept of urban resilience has found a new way to improve the ability of a city to absorb and resolve risks. However, the existing literature on the evaluation of urban resilience is mostly developed from a static perspective, lacking a systematic and dynamic understanding of the level of urban resilience. Therefore, this paper takes Hunan Province as the research object, determines the resilience evaluation indicators, collects the data of each indicator by using the observation method and the literature method, then chooses the comprehensive index method and other methods to measure the urban resilience level of Hunan Province in the years of 2010–2021, and observes the dynamic changes in the resilience level. And, we use the GeoDetector model to detect the dominant factors affecting the urban resilience level and the interaction between these factors. The results of this study show that: (1) The level of urban resilience in Hunan Province shows a steady upward trend from 2010 to 2021, but cities with low resilience levels hold a dominant position. Among all subsystems, the level of urban economic resilience is the highest. (2) From 2010 to 2021, the level of urban resilience in Hunan Province indicates a stepwise spatial structure in the spatial pattern, gradually decreasing from east to west. (3) The urban resilience of Hunan Province from 2010 to 2021 has a significant spatial agglomeration effect, mainly manifested as "L-H type" agglomeration and "L-L type" agglomeration. (4) The spatio-temporal differentiation of urban resilience is mainly caused by economic and social factors, while ecological, institutional, and infrastructure factors have a relatively small influence on the level of urban resilience. The interaction of impact factors will have a more significant influence on urban resilience. The research results of this article are of great significance for urban resilience construction in Hunan Province and even the whole country. © 2023 by the authors.	2023	10.3390/ijgi12100391	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85175491156&doi=10.3390%2fijgi12100391&partnerID=40&md5=db8ff34706f7dec3466e87c25fc72db7	GeoDetector model; Hunan Province; impact factors; spatial autocorrelation analysis; spatio-temporal differentiation; urban resilience assessment	Y	N	Y	variation over time	N.A.	city	administrative boundary	cological; Economic, Social, Institutional; Infrastructural;	N.A.
175	Huang H.; Zhou S.; Wang W.; Li R.; Qin T.; Yu F.	Study on the evaluation method and system of urban resilience in China	With the rapid development of cities and urban agglomerations, the operation of cities is becoming increasingly complicated, and the risks of urban safety are expanding, which make cities prone to become the place where disasters and accidents occur. Resilient cities can better adapt to changing environment, cope with uncertain risks, and achieve safe and sustainable development. In this paper, the urban resilience model and evaluation techniques were studied, quantitative analysis model of urban resilience was constructed. An urban resilience multi-dimensional evaluation index system and evaluation methods and criteria suitable for Chinese cities were established. The method of urban resilience analysis and optimization simulation was proposed, which included mechanism analysis, scenario construction, and strategy optimization. Based on GIS system, the resilient city evaluation and comprehensive integrated management platform were developed, and demonstration applications were carried out. The results provide favorable scientific and technological support for decision-making of urban safety management and construction of resilient cities. © 2023, The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature.	2023	10.1007/s10669-023-09926-x	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85167346861&doi=10.1007%2fs10669-023-09926-x&partnerID=40&md5=0dba2db63c0aa8887b958df96301077a	Evaluation criteria; Index system; Integrated technology platform; Resilience evaluation; Resilient cities	Y	N	N	current state	N.A.	city	N.A.	urban space; urban engineering; urban managemetn; urban society	N.A.
177	Liu W.; Zhou J.; Li X.; Zheng H.; Liu Y.	Urban resilience assessment and its spatial correlation from the multidimensional perspective: A case study of four provinces in North-South Seismic Belt, China	Modern cities are facing increasingly complex challenges, and assessing urban resilience is crucial to improve their ability to withstand various types of shocks and disasters, especially in the China's North-South Seismic Belt with frequent tectonic activities and natural disasters. To address this issue, this study determined the weights of the assessment system based on the entropy weight method, and evaluated the urban resilience of four provinces in China's North-South Seismic Belt in multiple dimensions from the perspectives of society, economy, infrastructure, and ecology. Furthermore, we systematically explored the spatiotemporal trends of urban resilience and its spatial correlation from 2011 to 2021. Lastly, the assessment results were validated and analyzed by four historical earthquake cases using national polar-orbiting partnership - visible infrared imaging radiometer suite (NPP-VIIRS) nighttime light data. The findings reveal that the average urban resilience index increased from 0.027 to 0.058 from 2011 to 2021, signifying a remarkable surge of 115.42%. Sichuan emerged as a consistent frontrunner in terms of urban resilience. Overall, the study area shows a spatial distribution pattern of higher urban resilience in the east and lower resilience in the west, due to the larger population and more developed economy in the east. However, the south has a higher average annual growth rate, while the north has a lower average annual growth rate. A notable observation is the gradual reduction in the coefficient of variation of urban resilience from 0.823 in 2011 to 0.751 in 2021, indicating a decline in the disparity of resilience levels. Meanwhile, Moran's I gradually increased from 0.2017 in 2011 to 0.4476 in 2021, signifying a progressive intensification in the spatial correlation of urban resilience and an evident propensity toward aggregation. By selecting shifts in the total nighttime light index (TNLI) during representative earthquake incidents as an indirect gauge of urban resilience levels, this study finds congruence with the assessment outcomes, thereby further substantiating the precision of the urban resilience evaluations. Policymakers should prioritize the allocation of resources to less resilient cities to improve their ability to withstand and recover from disaster events. The urban resilience assessment system in this study, despite its multidimensionality, may still not be able to fully cover all the factors affecting urban resilience. This study provides a significant decision-making basis for policymakers in urban development and disaster response, as well as a useful reference for building a more robust and sustainable urban future. © 2023 Elsevier Ltd	2024	10.1016/j.scs.2023.105109	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85179628404&doi=10.1016%2fj.scs.2023.105109&partnerID=40&md5=bf5bc6c76ff637bd30483c54dd8292ca	Evolution analysis; Nighttime lights; North-South Seismic Belt, China; Spatial correlation; Urban resilience assessment	Y	N	Y	variation over time	N.A.	province	administrative boundary	Social, Economic; Infrastructure; Ecological	N.A.
178	Mitrović S.; Vasiljević N.; Pjanović B.; Dabović T.	Assessing Urban Resilience with Geodesign: A Case Study of Urban Landscape Planning in Belgrade, Serbia	Resilient cities have emerged as novel urban ecosystems that respond to the increasing challenges of contemporary urban development. A new methodological approach is needed to measure and assess the degree of resilience of the urban landscape during the ongoing planning process, considering different planning and design scenarios. Based on this consideration, the first attempt of this study was to develop a resilience index that summarizes the application of resilience theory in urban landscape planning. Is geodesign an appropriate tool to assess urban resilience? This was the main research question and the topic of the workshop "IGC—Resilient City of Belgrade" at the Faculty of Forestry, University of Belgrade (Master Landscape Studio). The main result of this research is a model for urban resilience assessment with IGC geodesign, which allows to measure scenario changes through developed resilience indicators (index), which are determined by a set of parameters (area, redundancy, diversity, porosity, carbon sequestration, edge type, edge length, etc.). The methodological approach allows quantifying the impact of adopted innovations in geodesign scenario proposals, which plays a crucial role in strengthening the connection between landscape planning and design. In the context of the novel urban ecosystem, future urban landscape planning should focus on resilience as a measure to achieve sustainable development goals, supported by geodesign as a collaborative and spatially explicit negotiation tool. © 2023 by the authors.	2023	10.3390/land12101939	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85175070045&doi=10.3390%2fland12101939&partnerID=40&md5=54f00ffea8221fd5acfc4ef00bf20c66	geodesign; geodesign; landscape planning; resilience assessment; resiliency index; urban landscape	Y	Y	N	scenario	N.A.	city	sample area	Landscape	N.A.

ID	AUTHORS	TITLE	ABSTRACT	YEAR	DOI	LINK	KEYWORDS	INDICATORS (Y/N)	FORMULA (explicit) (Y/N)	MAP (Y/N)	TIMESCALE	RESILIENCE PHASE/ABILITY	SPATIAL SCALE	SPATIALIZATION METHOD	RESILIENCE DIMENSIONS	RESILIENCE CAPACITIES
179	Narieswari L.; Sitorus S.R.P.; Hardjomidjojo H.; Putri E.I.K.	Spatial Dynamic Model of Index-Based Disaster Resilience	Measurement and development of resilience are essential in disaster risk reduction programs. Furthermore, efforts are needed to measure resilience baselines to track changes over time and compare areas for monitoring and evaluating resilience development. Therefore, this study identified dimensions and indicators for measuring resilience using a statistical approach and developed an index-based spatial resilience model in a web-GIS environment. This paper presents the spatial distribution of urban resilience to disasters in Semarang City at the sub-district level. Factor analysis showed that 21 selected indicators could represent five dimensions of resilience: social, economic, infrastructure, environmental, and institutional. Furthermore, the model results showed that 88% of the sub-districts were in the moderate resilience class. The spatial distribution of each dimension showed considerable heterogeneity in its coastal and plain areas (city center) as well as better resilience in the social and infrastructure dimensions than in its hilly areas. The hilly areas in the west have relatively better resilience than those in the east. These results can be used as a reference in managing resilience to disasters. The model presents a spatial distribution of resilience based on an index that quickly provides an overview of the conditions and determines priorities for increasing resilience in supporting disaster risk reduction programs. © 20XX ITB, ASPI dan IAP.	2022	10.5614/jpwk.2022.33.3.7	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85147825695&doi=10.5614%2fjpwk.2022.33.3.7&partnerID=40&md5=31ff3f28f36252cf6909c0d2fa64e714	Disasters; resilience indicators; spatial distribution	Y	N	Y	scenario	N.A.	sub-district	administrative boundary	Social, economic, Infrastructure,Enviromental, Institutional	N.A.
182	Sebestyén V.; Trájer A.J.; Domokos E.; Torma A.; Abonyi J.	Objective well-being level (OWL) composite indicator for sustainable and resilient cities	Well-being is a critical element of the 2030 Agenda for Sustainable Development Goals. Given the complexity of the concept of well-being, it follows that its measurement requires complex, multivariate methods that can characterize the physical, economic, social and environmental aspects along with the mental state of a city. Although it is not sufficient to carry out settlement-level analyses to make cities inclusive, safe, resilient and sustainable. It is necessary to understand patterns within settlements. This work aims to present how the urban macrostructure of urban well-being indicators can be estimated based on GIS-based multilayer analysis. Open-source data, e.g. road networks, points of interest, green spaces and vegetation, are used to estimate urban well-being parameters such as noise levels, air quality and health-related impacts supplemented by climate models to assess urban resilience and sustainability. The proposed methodology integrates 24 models into six categories, namely walkability, environment, health, society, climate change and safety, which are weighted based on a multilevel Principal Component Analysis to minimize information loss for aggregated composite indicators. The study revealed two main components of the macrostructure related to well-being in the studied city: one related to the geometrical features and the other can be derived from the structure of the natural environment. In Veszprém a natural restoration of the detached house area, industrial area and downtown is recommended including developments with green and blue infrastructural elements and nature-based solutions. © 2023 The Author(s)	2024	10.1016/j.ecolind.2023.111460	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85181885066&doi=10.1016%2fj.ecolind.2023.111460&partnerID=40&md5=f3d7871570b5c3ba6b13d911c9e2571d	Composite indicator; Resilience enhancement; Sustainable city; Urban macrostructure; Well-being	Y	Y	Y	current state	N.A.	city	unit-pixel	N.A.	N.A.
185	Suárez M.; Rieiro-Díaz A.M.; Alba D.; Langemeyer J.; Gómez-Baggethun E.; Ametzaga-Arregi I.	Urban resilience through green infrastructure: A framework for policy analysis applied to Madrid, Spain	Urban resilience and how to assess it have become main policy objectives in the face of accelerated climate and other global environmental change. We develop a conceptual framework and an assessment tool to analyse how green infrastructure policies contribute to urban resilience and discuss barriers and opportunities for implementation. The conceptual framework is designed to analyse how resilience is fostered through six resilience factors: diversity, self-sufficiency and autonomy, polycentric governance, social cohesion, learning and innovation, and social-ecological justice. The assessment tool consists of a resilience index composed of 30 indicators. We use the capital city of Madrid, Spain, as a case study. Our results suggest that planning policies that focus on vulnerable neighbourhoods and include mechanisms for citizen engagement are the policies that most effectively foster urban resilience. We also identified that financing and political will are major barriers for the implementation of resilience policies. We assume that the proposed framework is suitable to assess to what extent local policies foster urban resilience and suggest further testing in other cities. © 2023 The Authors	2024	10.1016/j.landurbplan.2023.104923	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85175145625&doi=10.1016%2fj.landurbplan.2023.104923&partnerID=40&md5=d657cfee781037cf5cf995232e5e52de	Policy analysis; Social-ecological justice; Urban green infrastructure; Urban resilience index	Y	Y	N	current state	N.A.	City	N.A.	Socio-cultural, governance system, Economic, Ecological,physical and technological	N.A.
187	Wang K.-F.; Lin S.-W.; Chen Y.-H.	Assessing urban resilience in China from the perspective of socioeconomic and ecological sustainability	Industrial development is a critical factor for the economic development of a country. This study applies the fuzzy Delphi method (FDM) and a dynamic analytic network process (DANP) to develop a tool for the assessment of the resilience of industrial areas in Taiwan from the common-pool resources (CPRs) perspective to enhance the resilience of industrial areas and also ensure the efficient use of common urban disaster prevention resources. This study is innovative and may facilitate the assessment of the resilience of industrial areas and the validation of interactions between urban resilience, industrial area resilience and CPRs. The influencers of the resilience of industrial areas can be categorized into 5 dimensions and 24 indicators. The five dimensions are vulnerability, urban environment, industrial environment, factory properties, and governance and adaptation. The governance and adaptation dimension is the most crucial, and the five indicators with the highest weights are emergency response and planning, management organization, supervision, employee awareness of disaster prevention, and industry type. The results indicate the importance of adaptation and governance and response to the importance of Ostrom's (2005) CPRs. The study can be used as a reference for countries assessing the resilience of industrial areas and developing adaptation strategies. © 2023, ALÖKI Kft., Budapest,	2023	10.15666/aeer/2104_37113736	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85166755435&doi=10.15666%2faeer%2f2104_37113736&partnerID=40&md5=f8feb1af54b88194d88860942d3b582e	dynamic analytic network process (DANP); fuzzy Delphi method (FDM); resilience assessment; resilience governance; resilient adjustment indicators	Y	N	N	current state	N.A.	city	N.A.	Vulnerability; Urban enviroment; Industrial enviroment; Industrial environment; Factory properties; Governance and adaptation	N.A.
214	Yang T.; Wang L.	Did Urban Resilience Improve during 2005–2021? Evidence from 31 Chinese Provinces	In the context of climate change, various natural disasters and extreme weather events are occurring with increasing frequency. In addition, large-scale urbanization in China poses serious challenges to disaster resilience. The convergence of climate change and large-scale urbanization has made the enhancement of urban resilience (UR) an important guideline for current urban development. This study analyzes the UR of 31 provinces in China during 2005–2021 through the entropy method. A UR evaluation index system is constructed from the perspective of population resilience, social resilience, economic resilience, safeguarding facility resilience, and ecological resilience. The results demonstrate the following: (1) The overall performance of UR in China is relatively low, with an average value of 0.2390. (2) Chinese provinces significantly differ in UR levels, with Beijing, Shanghai, Tianjin, Zhejiang, Jiangsu, and Fujian being the top performers and Guangxi, Yunnan, Xinjiang, Gansu, and Tibet being the bottom. (3) From 2005 to 2021, the average UR value of the 31 Chinese provinces significantly improved. (4) Generally, the eastern, middle, and western regions exhibit relatively high, medium, and low average UR values, respectively. These research findings provide valuable references for Chinese policymakers to adopt measures for promoting UR enhancement and urban safety. © 2024 the authors.	2024	10.3390/land13030397	10.3390/land13030397	Chinese provinces; disaster resilience; entropy method; indicators; urban resilience	Y	N	Y	variation over time	Preparedness Response Recovery	province	administrative boundary	Population, Social, Economic, Safeguarding facility, Ecological	robustness, rapidity, redundancy, resourcefulness, adaptability, diversity, and biodiversity

ID	AUTHORS	TITLE	ABSTRACT	YEAR	DOI	LINK	KEYWORDS	INDICATORS (Y/N)	FORMULA (explicit) (Y/N)	MAP (Y/N)	TIMESCALE	RESILIENCE PHASE/ABILITY	SPATIAL SCALE	SPATIALIZATION METHOD	RESILIENCE DIMENSIONS	RESILIENCE CAPACITIES
215	Khatibi H.; Wilkinson S.; Sweya L.N.; Baghersad M.; Dianat H.	Navigating Climate Change Challenges through Smart Resilient Cities: A Comprehensive Assessment Framework	The rapid increase in the global population is contributing to the urgent challenges we face in ensuring the sustainability of our planet. This demographic shift, which gained momentum in the 1990s, is closely linked to a surge in natural disasters, both in terms of their frequency and severity. The quest for resources and improved quality of life, including the need for housing and essential services, has compounded these challenges. With the world's population projected to double by 2050, and approximately two-thirds of this population expected to reside in urban areas, we are facing a complex web of interconnected issues that will significantly magnify the impacts of climate change-induced disasters. It is imperative that we build resilient cities capable of withstanding and adapting to these changes. However, the growing complexity of urban services and the necessity for integrated management raise questions about the preparedness of these resilient cities to comprehend and address the multifaceted challenges posed by climate change. In response to these critical concerns, this study endeavors to address the intersection of resilience and climate change. We propose the development of a Smart Resilient City Assessment Framework, comprising two core components: resilience re-evaluation and smartness evaluation. Each component consists of eight essential steps. The culmination of these steps results in a semi-quantitative index that accurately reflects the city's position regarding resilience and smartness in the face of climate change-related disasters. To demonstrate the framework's practicality and suitability, we present results from a hypothetical scenario focusing on water supply management, a critical aspect of climate change adaptation. The framework equips city managers with the necessary tools to re-evaluate their cities' resilience, evaluate their capacity to address climate change-induced challenges, and make informed decisions on integrating resilience and smart solutions to pave the way for a more sustainable and climate-resilient future. © 2024 by the authors.	2024	10.3390/land13030266	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85189141862&doi=10.3390%2fland13030266&partnerID=40&md5=beb80e2def204193968501ed6701e43b	assessment framework; assessment tools; climate change; smart city; smart resilient cities; urban resilience	Y	N	N	current state	N.A.	city	N.A.	Enviromental	Connectivity Redundancy Robustness Independence

Additional sources

ID	AUTHORS	TITLE	ABSTRACT	YEAR	LINK
216	Natural Capital Project - Stanford University, University of Minnesota, Chinese Academy of Sciences, The Nature Conservancy, World Wildlife Fund, Stockholm Resilience Centre and the Royal Swedish Academy of Sciences	InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs		2025	https://naturalcapitalproject.stanford.edu/software/invest
217	Città Metropolitana di Torino et al.	EU LIFE+ Project "Soil Administration Models 4 Community Profit (SAM4CP)"		2018	http://www.sam4cp.eu/ https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE13-ENV-IT-001218/soil-administration-models-4-community-profit
218	Minciardi M. R.; Ciadamidaro S.; Rossi G. L.; Alberico S.; Grasso S.; Vayr P.	Modalità tecniche per l'analisi e il miglioramento della reticolarità ecologica del territorio. Applicazione al territorio della Città metropolitana di Torino, RT/2019/3/ENEA.	The progressive loss of connectivity between the natural elements that characterizes the territory of our Country requires the implementation of policies aimed not only to protect but also improve ecological networking. Tools that can effectively and objectively guide planning and design are necessary, including identification of intervention priorities. The research carried out made it possible to highlight how, starting from maps of Land Use with a detailed Legend, it is possible to outline a process starting from the analysis of the existing ecological reticularity, up to to the definition of procedures for the planning and design of its implementation and improvement. From the sample area of the Morainian Amphitheater of Ivrea (TO), the reticular functionality of the entire territory of the Province of Turin has been defined through the attribution of ecological values, in terms of Naturalness, Relevance for Conservation, Fragility, Extroversion and Irreversibility to each of the types of land use existing in study area. Applied research, carried out for and in collaboration with the Metropolitan City of Turin, led to a methodological proposal that represents one of the reference documents that became part of the Guidelines of the Green System and of the Provincial Ecological Network provided for art. 4 and 35 of the Implementation Rules of the Provincial Coordination Territorial Plan.	2019	https://iris.enea.it/bitstream/20.500.12079/6837/1/RT-2019-03-ENEA.pdf
219	Regione Piemonte	DGR n. 52-1979 del 31/7/2015, Legge regionale del 29 giugno 2009, n. 19 "Testo unico sulla tutela delle aree naturali e della biodiversità'". Approvazione della metodologia tecnico-scientifica di riferimento per l'individuazione degli elementi della rete ecologica regionale e la sua implementazione		2015	
220	Governo italiano	Codice dei beni culturali e del paesaggio (D.Lgs. 42/2004). Gazzetta Ufficiale della Repubblica Italiana, 24 febbraio 2004, n. 45		2004	
221	SNPA	Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2024, Report ambientali SNPA, 43/2024		2024	https://www.snpambiente.it/temi/suolo/consumo-di-suolo-dinamiche-
222	U.S. Forest Service, Davey Tree Expert Company; The Arbor Day Foundation; Urban and Community Forestry Society; International Society of Arboriculture; Casey Trees; SUNY College of Environmental Science and Forestry	i-Tree		2006	https://itreetools.org/
223	McGarigal K.; Cushman S.A.; Ene E.	FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors; available at the following web site: https://www.fragstats.org		2023	https://www.fragstats.org

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Appendix B – Extended Catalogue

Built Environment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x					1	0	Not aligned with urban resilience-focused evaluation	**Building density**	Buildings	Density of buildings within a selected area expressed with the Floor area ratio (ratio of a building's total floor area to the size of land upon which it is built)	2	97, 182	negative	$N = \frac{A_s}{A_t}$ N = floor area ratio (building density) A_s = total floor area of the building (the sum of all floor spaces in the building) A_t = the size of the parcel upon which the building is constructed	%	sub-district
x			x		2	1		**Businesses and retail establishments**	Buildings	Concentration of sales facilities - categorized by size when possible - in relation to the resident population	1	214	positive	$N = \frac{S}{R}$ N = business and retail establishments S= number of sales facilities in the selcted area P = total population in the selected area	unit/10,000 inh.	district
x					3	0	Not relevant at district scale	**Energy performance of buildings**	Buildings	Energy efficiency of the existing building stock	1	30	postive	$N = \frac{O}{C}$ N = energy performance O = amount of output the appliance delivers per unit area, per year C = amount of energy it consumes to deliver this output per unit area per year	%	sub-district
x					4	1		**Informal settlements at risk**	Buildings	Surface occupied by informal settlements (nomadic camps, illegal camps...) in high-risk areas	2	30, 179	negative	$N = \frac{A_l}{A_t}$ N = informal settlements at risk A_r = area occupied by informal settlements in high risk area A_t = total surface of the selected area	%	district
x	x				5	0	Not aligned with urban resilience-focused evaluation	**Major accident hazard establishments**	Buildings	Presence of estabilishments that fall into the Seveso-III EU Directive	1	187	negative	$N = \frac{A_S}{A_t}$ N = major accident hazard establishment A_S = surface of the Seveso zone A_t = total surface of the selected area	%	urban
x					6	0	Not aligned with urban resilience-focused evaluation	**Buildings completed after 1971**	Buildings	Percentage of buildings completed after 1971, the year when the seismic safety law was enacted in Italy, compared to the overall building stock in a selected area.	2	58, 214	not defined	$N = \frac{A_b}{A_t}$ N = proportion of buildings built after 1980 A_r = area occupied by buildings built after 1980 A_t = tortal area of the building stock	%	sub-district
x			x		7	0	Not aligned with urban resilience-focused evaluation	**Industrial area**	Buildings	Proportion of industrial areas within a selected area	1	187	not defined	$N = \frac{A_i}{A_t}$ N= proportion of industrial area F_t = sum of surface of factories in the selected area A_t = total surface of the selected area	%	district
		x			8	1		**Local Associations**	Collaboration	Number and location of active local associations	2	173, 214	positive	$N = \frac{L}{A_t}$ N= local associations L = number of local associations in the selcted area P = total population in the selected area	unit/10,000 inh.	sub-district
		x			9	0	Not aligned with urban resilience-focused evaluation	**Certified disabilities**	Demography	Proportion of individuals who have been officially recognized and documented as having a disability by relevant authorities compared to the population of a selected area	2	179, 214	not defined	$N = \frac{D}{P}$ N = certified disabilities D = inhabitants with certified disabilities R = total population in the selected area	%	sub-district
x		x			10	1		**Home ownership**	Demography	Proportion of households that own their residence compared to those who rent or occupy their homes through other means within a selected area	4	11, 126, 179, 214	positive	$N = \frac{O}{H}$ N = home ownership O = number of home-owning households H= total number of households	%	district
		x	x	x	11	0	Difficult to Spatially Represent	**Minimum living standard**	Demography	Proportion of the population receiving the minimum wage in the city	1	149	negative	$N = \frac{M}{P_w}$ N= minimum living standard M = number of inhabitants receiving minimum wage P_w = total working-age population	%	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
		x			12	1		**Natural growth**	Demography	Difference between the number of births and the number of deaths in a given population over a specific period. It measures the organic increase or decrease in population size, excluding migration	7	37, 48, 86, 100, 120, 177, 214,	positive	$N = CBR - CDR$ *N = Natural Growth or Natural Increase Population (NIP)* *CBR= Crude Birth Rate* *CDR= Crude Death Rate*	count	district
x		x			13	1		**Population density**	Demography	Number of resident people per unit of area	14	11, 30, 31, 64, 97, 100, 103, 120, 126, 149, 173, 182, 191, 214	negative	$N = \frac{P}{A}$ *N = density of resident population* *P= inhabitants in the selected area* *A= total surface of selected area*	unit/km^2	sub-district
		x			14	1		**Population with higher education**	Demography	Proportion of the population with higher education	4	58, 64, 97, 214	positive	$N = \frac{H}{P}$ *N = population with higher education* *H = inhabitants with higher education* *P = total population in the selected area*	%	sub-district
		x	x		15	1		**Unemployment Rate**	Demography	Number of beds in various medical and health institutions compared to the resident population whithin a selected area	14	36, 37, 48, 62, 64, 86, 97, 126, 131, 149, 152, 173, 177, 214	negative	$N = \frac{U}{P}$ *N = unemployment rate* *U = number of urban registered unemployed* *P= total population in the selected area*	%	urban
	x				16	1		**Air quality improvement**	Ecosystem services	Hourly amount of pollution removed by the urban forest, and associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter 2.5 (<2.5 microns).	3	9, 21,150, 223	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x		x		17	1		**Carbon Storage and Sequestration**	Ecosystem services	Amount of carbon retained in ecosystems, primarily in vegetation, soils, and wetlands	3	9, 44, 178, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district
	x				18	1		**Habitat quality**	Ecosystem services	This supporting ecosystem service assesses the quality of natural ecosystems for maintaining biological and genetic diversity on Earth	3	21, 44, 150, 216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
	x	x			19	1		**Recreation opportunities**	Ecosystem services	Predictions on the spread of person-days of recreation, based on the locations of natural habitats and other features that factor into people's decisions about where to recreate	1	44, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x	x			20	1		**Urban Cooling**	Ecosystem services	Heat mitigation based on shade, evapotranspiration, albedo, and distance from cooling islands. The index is used to estimate a temperature reduction by vegetation	1	21, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district
	x				21	1		**Urban Stormwater Retention**	Ecosystem services	Provides information on two ES related to stormwater management: runoff retention, and groundwater recharge	3	21, 36, 150, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x				22	1		**Water Availability**	Ecosystem services	This is a regulation ecosystem service provided by aquatic and terrestrial ecosystems, which filter and decompose organic waste entering inland waters and coastal/marine ecosystems, thus contributing to potable water supply	2	21, 44, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	urban
	x				23	1		**Water Yield**	Ecosystem services	Estimates the relative contributions of water from different parts of a landscape (Annual or seasonal water yield)	2	21, 150, 216	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x		x			24	1		**Accommodation places**	Emergency	Presence of accomodation places (hotels, hostels, B&B, etc.)	11	11, 48, 62, 86, 100, 103, 120, 149, 152, 173, 214	positive	$N = \frac{A}{P}$ *N= Aùaccomodation places* *P = number of accomodation places (hotels, hostels, B&B...)* *P = total population in the selected area*	unit/1'000 inh.	urban
		x		x	25	0	Difficult to Spatially Represent	**Emergency medical treatment capability**	Emergency	Number of doctors, nurse anche technicians, specifically intended for emergency intervention in the selected area	1	175	positive	$N = D$ *N= emergengy medical treatment capability* *D = number of doctors, nurses and technicians, specifically intended for emergency intervention in the selected area*	count	urban
x		x		x	26	1		**Emergency shelters**	Emergency	Temporary housing facilities established to provide refuge and support for individuals and families during emergencies	7	11, 31, 36, 126, 175, 187, 191	positive	$N = \frac{E}{S}$ *N= emergency shelters* *E = capacity of temporary housing units available* *P= total population of the selected*	unit/inh.	urban
x				x	27	1		**Evacuation routes**	Emergency	Designated routes planned to safely guide individuals away from danger zones during emergencies	2	31, 36	positive	$N = \frac{L}{A}$ *N= evacuation routes* *L= lenght of evacuation routes* *A= total surface of the selected area*	km/km^2	district
x		x		x	28	1		**Fire and police stations**	Emergency	Presence of fire departement station and police station	4	36, 58, 182, 187	positive	$N = \frac{S}{P}$ *N = fire and police station* *S = sum of fire and police department station in the selected area* *P = total populaiton of the selected area*	count	district
		x		x	29	0	Difficult to Spatially Represent	**Public Administration Personnel**	Emergency	Number of public administration (e.g. municipality) employees dedicated to managing administrative functions across critical areas (such as health, safety, urban planning, and disaster management)	2	58, 97	positive	$N = \frac{E}{P}$ *N= public administration personnel* *C= number of public administration employees* *P = total populaiton in the selected area*	count/1,000 inh.	urban
		x		x	30	1		**Trained population**	Emergency	Total amount of water consumed by both the resident population and non-residents in a selected area during a year	2	36, 179	positive	$N = \frac{S}{P}$ *N= trained population* *S = number of inhabitants who have attended safety courses* *P= total population in the selected area*	count/1,000 inh.	urban
x		x		x	31	1		**Warning and reporting systems**	Emergency	Precence of warning and reporting systems/hazard prediction capable of help in the managing of the emergence	5	36, 126, 175, 179, 214	positive	$N = \frac{W}{A}$ *N= warning and reporting system* *W= number of warning and reporting systems/hazard prediction able to help manage the emergency* *A= total surface of the selected area*	$unit/km^2$	urban

Built Environment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x	x				32	1		**Historic, cultural, and natural heritage assets and sites**	Heritage	Number of sites and buildings of historical, artistic, cultural or natural interest that define a community's heritage, such as: assets with natural beauty, geological singularity or historical memory (excluding monumental trees); villas and any historic parks; buildings of aesthetic and traditional value, including historic centers; panoramic beauties and viewpoints.	2	120, 149, developed based on 220	positive	$N=\sum_{k=0}^{n} w_k$ *N= number of sites and buildings of historical, artistic, cultural or natural interest* *w = number of assets with natural beauty, geological singularity or historical memory (excluding monumental trees); villas and any historic parks; buildings of aesthetic and traditional value, including historic centers; panoramic beauties and viewpoints.* *n= total number of the elements consider*	count	sub-district
x		x		x	33	1		**Religious facilities**	Heritage	Presence of religious facilities/services	2	58, 120	positive	$N=\frac{R}{P}$ *N= religious facilities* *R= number of religious facilities* *P= total population in the selected area*	unit/10,000 inh.	sub-district
		x	x		34	0	Difficult to Spatially Represent	**Disposable income**	Income	Urban disposable income per capita	17	11, 37, 48, 62, 64, 86, 90, 97, 100, 103, 131, 149, 152, 173, 177, 191, 214	positive	$N=I$ *N= disposable income* *I= net income per capita*	€/inh.	urban
			x	x	35	0	Not aligned with urban resilience-focused evaluation	**GDP**	Income	Gross domestic product	5	37,48,90,103,191	positive	$N=GDP$ *N=Gross Domestic Product:* *GDP= Consumption + Investment + Government Spending + Net Exports*	€	regional
			x	x	36	0	Not aligned with urban resilience-focused evaluation	**GDP - per capita**	Income	Gross domestic product per capita	13	11,37,48,62,86,97,100,131,149,173,177,191,214	positive	$N=GDP\ per\ capita$ *Groos Domestic Product:* *GDP= Consumption + Investment + Government Spending + Net Exports*	€/inh.	regional
		x	x		37	1		**Housing prices**	Income	Market value of housing properties in the residential sector for each territorial zone	1	121	positive	$N=P$ *N= housing prices* *P = average price per square meter referring to residantial buildings*	€/m^2	sub-district
			x	x	38	0	Not aligned with urban resilience-focused evaluation	**Local tax per capita**	Income	Amount of local tax per capita	6	36,37,48,58, 62, 152	not defined	$N=\frac{T}{P}$ *N= local tax per capita* *T = sum of different form of taxes* *P= total population of the selected area*	€/inh.	urban
				x	39	1		**Access to the Highway**	Infrastructures and network	Population living within a specified distance from a highway entrance or exit	3	100, 130, 173	positive	$N=\frac{Z}{P}$ *N= access to the highway* *H= number of inhabitants within a specified distance from a highway access* *P = total population in the selected area*	%	district
x					40	1		**Cycling infrastructure**	Infrastructures and network	Extent of bike lanes and shared paths within a selected area	1	30	positive	$N=\frac{L}{A}$ *N= cycling infrastructure* *L = lenght of bike lanes in the selected area* *A = surface of the selected area*	km/km^2	sub-district
x	x			x	41	1		**Density of sewers**	Infrastructures and network	Surface covered by sewers system over the total area	1	11	positive	$N=\frac{S}{A}$ *N= density of sewers in buit-up area* *S = area covered by sewers network* *A= total surface of the selected area*	%	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x	x			x	42	1		**Drainage system in built-up areas**	Infrastructures and network	Surface covered by drainage system over the total area	6	37, 48, 58, 86, 173, 187	positive	$N=\frac{D}{A}$ *N= drainage system in buit-up areas* *D = area covered by drainage system* *A = total surface of the selected area*	%	district
x				x	43	0	Not aligned with urban resilience-focused evaluation	**Fixed-line phones**	Infrastructures and network	Density of fixed phone users within a selected area calculated as the number of fixed phone connections relative to the total resident population	2	126, 173	to be defined	$N=\frac{N}{P}$ *N= fixed-line phones* *N= number of fixed phone connections* *P= total population in the selected area*	unit/inh.	urban
x				x	44	0	Data is not readily available at district scale	**Gas penetration**	Infrastructures and network	Proportion of area served by a natural gas supply network over the total area	4	86, 97, 173, 214	to be defined	$N=\frac{G}{A}$ *N= gas penetration* *G = area covered by gas network* *A = total surface of the selected area*	%	urban
x		x		x	45	0	Not aligned with urban resilience-focused evaluation	**Internet users**	Infrastructures and network	Area that is served by broadband internet infrastructure	7	11, 38, 48, 152, 62, 100, 214	positive	$N=\frac{B}{A}$ *N= Internet users* *I= area covered by broadband Internet service* *A= total surface of the selected area*	%	urban
x		x			46	0	Not aligned with urban resilience-focused evaluation	**Mobile phones**	Infrastructures and network	Proportion of mobile phone users to the resident population	8	64, 103, 152, 173, 37, 48, 97, 214	positive	$N=\frac{K}{P}$ *N= mobile phones* *N= number of mobile phone users* *P= total population in the selected area*	unit/10,000 inh.	urban
x		x			47	0	Not aligned with urban resilience-focused evaluation	**Parkings**	Infrastructures and network	Proportion of parking area over the selected area	2	30, 120	positive	$N=\frac{P}{A}$ *N= parkings* *P= surface of parkings in the selected area* *A= total surface of the selected area*	%	sub-district
x				x	48	1		**Public transportation**	Infrastructures and network	Distribution and concentration of public transport supply, availability and number of public transport stops, encompassing various modes of transportation (buses, trains, trams, etc.)	7	11, 62, 64, 86, 97, 100, 173	positive	Kernel Density formula	unit/m^2	sub-district
x				x	49	1		**Public water fountains**	Infrastructures and network	Distribution and concentration of publicly accessible water fountains	1	120	positive	Kernel Density formula	unit/m^2	sub-district
x				x	50	0	Not aligned with urban resilience-focused evaluation	**Road area**	Infrastructures and network	Proportion of land allocated to roads (including urban streets, highways, and other transportation pathways) over the total area	2	86, 126	positive	$N=\frac{R}{A}$ *N= road area* *R = area covered by roads* *A = total surface of the selected area*	%	district
x				x	51	1		**Walkability Index**	Infrastructures and network	It measures the level of mobility and accessibility for pedestrians in a selected area	3	31, 121, 182	positive	Formula depends on the variables considered, which vary according to each specific case	adimensional	sub-district
x				x	52	0	Not aligned with urban resilience-focused evaluation	**Water service coverage**	Infrastructures and network	Proportion of area that has access to a reliable and sufficient supply of drinking water for basic needs	7	11, 30, 37, 48, 86, 97, 215	positive	$N=\frac{W}{A}$ *N= water service coverage* *W= area covered by urban water service* *A = total surface of the selected area*	%	urban

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
x				x	53	1		**Waterlogging**	Infrastructures and network	Proportion of areas that are prone of excessive accumulation of water over the total area	1	28	negative	$N = \frac{W}{A}$ *N= waterlogging* *W= area at waterlogging risk* *A= total surface of the selected area*	%	sub-district
x	x				54	1		**Land use diversity**	Land use	Variety and mixture of different types of land uses	2	21, 150	positive	$H = -\sum_{i=1}^{S} pi\ Ln\ pi$ *Pi = (number of polygons of "i" land use classes/ (total number of polygons S)*	adimensional	sub-district
	x				55	1		**Landscape fragmentation**	Landscape	Degree to which the landscape impedes movement among different patches	1	178, 222	negative	$F = LDI = 1 - \sum_{i=1}^{S} \left(\frac{a_i}{A}\right)$ *LDI= Landscape Division Index* a_i *= area of the iii-th patch* *A = total landscape area*	adimensional	sub-district
	x				56	1		**Shannon diversity index-SHDI (Landscape diversity metric)**	Landscape	It measures the uniformity of different land use patches within a landscape structure. The higher the value of H, the higher the diversity of species in a particular community	3	121, 178, 36, 222	positive	$H = -\sum_{i=1}^{S} pi\ Ln\ pi$ *Pi = (number of polygons of "i" patches / (total number of polygons S)*	adimensional	sub-district
	x			x	57	1		**Forest cover**	Natural/green spaces	Proportion of forest coverage over the total area	3	37, 48, 214	positive	$N = \frac{F}{A}$ *N= forest cover* *F= forest area* *A= total surface of the selected area*	%	sub-district
	x				58	1		**Green coverage (natural and seminatural areas)**	Natural/green spaces	Proportion of green covered areas (natural and seminatural) over the area	5	37, 48, 58, 126, 173	positive	$N = \frac{L}{A}$ *N= natural and seminatural areas* *L= surface of Land use/Land cover classes related to natural and seminatural areas in the selected area* *A= total surface of the selected area*	%	sub-district
	x			x	59	1		**Green urban spaces**	Natural/green spaces	Lot area occupied by green urban spaces compared to the resident population whithin a selected area	6	30, 37, 48, 126, 149, 173	positive	$N = \frac{G}{P}$ *N= green urban spaces* *G=surface of green urban spaces in the selected area* *P= total population in the selected area*	m^2/inh.	sub-district
x	x				60	1		**Imperviousness**	Natural/green spaces	Proportion of impermeable surfaces that prevents the infiltration of water into the ground, over the total area	4	36,44,149, 178	negative	$N = \frac{I}{A}$ *N = imperviousness* *I=impermeable areas* *A= total surface of the selected area*	%	sub-district
	x				61	1		**NDVI**	Natural/green spaces	Normalized difference vegetation Index. It provides informations on the presence and condition of vegetation on the Earth's surface	3	100, 177, 182	positive	$N = \frac{NIR - Red}{NIR + Red}$ *N= Normalized Difference Vegetation Index, where Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively*	adimensional	sub-district
	x			x	62	1		**Protected areas**	Natural/green spaces	Proportion of Protected areas sourface over the total area	1	30	positive	$N = \frac{P}{A}$ *N= protected areas* *P= surface of the protected areas* *A= total surface of the selected area*	%	district
x	x				63	1		**Public Urban Trees**	Natural/green spaces	The ratio of publicly managed urban trees to the total population in the selected area	1	120	positive	$N = \frac{T}{P}$ *N= public urban trees* *T= number of public urban trees* *P=population in the selected area*	unit/100 inh.	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x				64	1		**Tree cover**	Natural/green spaces	Proportion of ground area covered by the canopy of trees	2	9, 173	positive	$N = \frac{C}{A}$ N= tree cover density C= area covered by tree canopies A= total surface of the selected area	%	sub-district
	x			x	65	1		**Wetland areas**	Natural/green spaces	Proportion of wetland areas over the total area	2	28, 214	positive	$N = \frac{W}{A}$ N= wetland area ratio W = surface of wetland A = total surface of the selected area	%	district
				x	66	1		**Plans and Strategies for CCA & DRR**	Planning and programming	Disaster management /Resilience/CCA plans or strategies	2	36, 126	positive	$N = X$ N= plans and strategues for CCA & DDR P= number of plans or strategies in the selected area	count	urban
			x	x	67	0	Difficult to spatially represent	**Investment in prevention, mitigation, answer systems**	Planning and programming	Proportion of investment in geohazard prevention and control, innovtive technologies for risk assessment, mitigation systems... Relative to GDP	2	126, 214	positive	$N = I/GDP$ N= investment in geohazard I= investments in hazard prevention, innovative technologies for risk assessment and mitigation systems GDP= Gross Domestic Product	%	regional
	x				68	1		**Air pollution**	Pollution	Number of days with concentrations above the local norm or standard for key criteria pollutants (NH_3, NOx, PM 2.5, PM 10, SO_x) in a selected area.	9	11, 30, 37, 48, 64, 97, 149, 152, 214	negative	$N = J$ N= air pollution J = number of days with concentrations above the local norm or standard for key criterion pollutants	days	district
	x				69	0	Not aligned with urban resilience-focused evaluation	**Noise pollution**	Pollution	Level of noise above EU standards: Lden>=55dB, Lnight>=50dB in a selected area	2	86, 182	negative	$N = K$ N= noise pollution K= level of noise above EU standards	dB	sub-district
	x				70	1		**Water pollution**	Pollution	Number of days exceeding Enviromental Quality Standards (water) in a selected area	1	126	negative	$N = K$ N= water pollution K= number of days exceeding Enviromental Quality Standards in the last year	days	district
x	x				71	0	Not aligned with urban resilience-focused evaluation	**Energy consumption**	Resources / Resources consumption	Total consumption of natural gas and electricity from distribution networks in a selected area	14	30, 36, 48, 64, 97, 120, 131, 149, 152, 100, 187, 214, 100	negativo	$N = \frac{E}{P}$ N = energy consumption E = energy consumption of the community in the selected area in a year P = total population in the selected area	toe*100 inh.	district
	x	x			72	1		**Local Agricultural Production Area**	Resources / Resources consumption	Proportion of land used for food production within a selected area.	4	21, 30, 131, 214	positive	$N = \frac{F}{R}$ N = local agricultural production area F = area used for food production A= total surface of the selected area	%	district
x	x				73	0	Not aligned with urban resilience-focused evaluation	**Renewable energy**	Resources / Resources consumption	Propoprtion of energy derived from renewable sources as part of the total gross energy consumption in a selected area	2	36, 149	positive	$N = \frac{R}{E}$ N = renewable energy E = energy consumption of the community in the selected area in a year (expressed in kWh) that comes from renewable sources E_c = energy consumption of the community in the selected area in a year	%	district
x	x				74	0	Not aligned with urban resilience-focused evaluation	**Water consumption**	Resources / Resources consumption	Total amount of water consumed by both the resident population and non-residents in a selected area during a year	12	30,36,48,62,100,120, 121, 131, 173, 187, 214, 215	negative	$N = \frac{K}{P}$ N= water consumption K = total amount of water consumed P= total population in the selected area	l/inh.*year	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
	x	x			75	1		**Accessibility to green urban spaces**	Services	Percentage of population with access to a green urban area less than 300m away	2	30, 185	positive	$N = \frac{G}{P}$ *N= accessibility to green urban spaces* *G= number of inhabitants living less than 300 m from green areas* *P= total population in the selected area*	%	sub-district
				x	76	1		**Beds in health institutions**	Services	Number of beds in various medical and health institutions compared to the resident population whithin a selected area.	8	36, 62, 86, 100, 103, 131, 177, 191	positive	$N = \frac{B}{P}$ *N= beds in health institutions* *B= number of bed in health centers and in health insititution* *P= total population in the selected area*	unit/inh.	urban
	x	x			77	0	Not aligned with urban resilience-focused evaluation	**Equipped recreational area**	Services	Total area dedicated to equipped recreational and sports facilities, regardless of whether they are located within green spaces or urban settings, available for the population in a selected area.	1	120	positive	$N = \frac{E}{P}$ *N= equipped recreational area* *A_r = sum of all equipped facility areas* *R = total population in the selected area*	m^2/inh.	sub-district
				x	78	1		**General practitioners**	Services	Number of general practitioners compared to the resident population whithin a selected area	7	11, 37, 48, 100, 131, 152, 179	positive	$N = \frac{D}{P}$ *N= general practitioners* *D=number of doctors* *P= total population in the selected area*	unit/10,000 inh.	urban
x				x	79	1		**Hospitals and health centers**	Services	Lot area occupied by hospitals and health centers relative to the number of inhabitants whithin a selected area	3	11, 173, 187	positive	$N = \frac{H}{A}$ *N = hospital and health centers* *H =lot area occupied by hospital and health centers* *A = total population in the selected area*	m^2/inh.	district
x		x	x		80	1		**Market Area**	Services	Lot area occupied by markets compared to the resident population whithin a selected area	1	120	positive	$N = \frac{M}{R}$ *N = market area* *M= lot area occupie dby markets* *R = total population in the selected area*	m^2/inh.	district
x	x				81	1		**Proximity Index**	Services	Proximity and accessibility to basic services, such as food supply, education, health, sport or cultural facilities	1	31	threshold value	$N = PI = \frac{S}{P}$ *N= proximity Index expressed as a percentage* *S= inhabitants near basic services* *R= total population in the selected area*	%	sub-district
x		x		x	82	1		**Proximity to hospitals**	Services	The estimated time required to reach the nearest hospital or health institution from the selected area.	1	126	negative	$N = T$ *N = proximity to hospitals* *T = time needed to reach the nearest hospital*	s	sub-district
x		x			83	1		**Public and Affiliated Educational facilities**	Services	Lot area occupied by public educational facilities (such as schools, colleges, and universities) relative to the number of inhabitants in a selected area	5	58, 97, 120, 179, 214	positive	$N = \frac{E}{P}$ *N = public and affiliated educational facilities* *E =lot area occupied by educational facilities* *P= total population in the selected area*	m^2/inh.	sub-district
x		x			84	1		**Public libraries**	Services	Lot area occupied by public libraries relative to the number of inhabitants in a selected area	1	58	positive	$N = \frac{L}{R}$ *N = public libraries* *L= lot area occupied by public libraries* *R= total population in the selected area*	m^2/inh.	sub-district
x		x			85	1		**Public or affiliated sports facilities**	Services	Lot area occupied by sport facilities relative to the number of inhabitants in a selected area	1	120	positive	$N = \frac{S}{P}$ *N = public or affiliated sport services* *S = lot area occupied by sport services* *P= total population in the selected area*	m^2/inh.	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
		x	x		86	1		**Social allowance**	Services	Proportion of population receiving income support from the government for basic needs	3	58, 103, 214	negative	$N = \frac{I}{P}$ *N= social allowance* *I= inhabitants receiving income support for basic needs from government* *P = total population in the selected area*	%	district
		x	x		87	1		**Social assistance**	Services	Proportion of population receiving social assistance	4	64, 126, 175,179	negative	$N = \frac{S}{P}$ *N= social assistance* *S= inhabitants receiving social assistance* *P= total population in the selected area*	%	district
x				x	88	1		**Brownfield sites**	**Buildings**	Surface and location of unused, abandoned, or underutilized areas, typically previously used for industrial or commercial purposes, which may have potential for redevelopment	added		negative	$N = \frac{B}{A}$ *N = brownfield sites* *B= total area covered by bownfield sites in the selected area* *A = total surface of the selected area*	%	sub-district
x				x	89	1		**Renovation of public buildings**	**Buildings**	Number and location of renovation interventions (e.g. energy efficiency upgrades ...) of public buildings	added		positive	$N = K$ *N= renovation of public buildings* *K= number of interventions in the selecte area*	count	district
		x		x	90	1		**Collaboration pacts**	**Collaboration**	Number and location of collaborative agreements with citizens for the shared management of buildings, schools, and public spaces	added		positive	$N = K$ *N= collaboration pacts* *K= number of collaboration pacts in the selected area*	count	district
		x			91	0	Not aligned with urban resilience-focused evaluation	**Aging index**	**Demography**	The number of the elderly aged 65 years and over, per 100 individuals younger than 14 years old in the specific population of a selected area	*added*		threshold value (100)	$N = \frac{A}{P}$ *N = age dependency ratio* *A = number of younger than 15 and older than 64* *P= total population in the selected area*	count	district
x		x		x	92	1		**Beds in Affiliated student housing**	**Demography**	Total number of available beds in student housing that is provided through agreements between educational institutions and housing providers (affiliated or subsidized housing)	added		positive	$N = \frac{H}{R}$ *N = number of beds in affiliated student housing* *H =number of beds in affiliated student housing* *P= global surface of the selected area*	%	sub-district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
		x			93	1		**NEET**	**Demography**	Proportion of Not in Education, Employment or Training (NEET) individuals on whithin the population of a selected area	added		negative	$N = \frac{N}{P}$ *N = NEET* *N_t =number of NEET individuals* *P= population of the same age group*	%	district
	x				94	1		**Crop Pollination (Pollinator Abundance)**	**Ecosystem services**	Ecosystem Service of regulation and provisioning that is fundamental for the productivity of many crops. Plant fertilization and, consequently, food production partly depend on wild pollinator species.	*added*	216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	sub- district
	x				95	1		**Crop production**	**Ecosystem services**	This provisioning ecosystem service (E.S.) is linked to human land use for productive purposes	*added*	216, 217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x				96	1		**Erosion Mitigation**	**Ecosystem services**	This regulation ecosystem service (E.S.) evaluates the capacity of healthy soils to reduce the removal of the topsoil layer (rich in organic matter) caused by surface runoff and rainfall	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
	x				97	1		**Nutrient Retention**	**Ecosystem services**	This regulation ecosystem service is provided by aquatic and terrestrial ecosystems that filter and decompose organic waste entering inland waters, coastal, and marine ecosystems, supporting potable water supply	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
x	x				98	1		**Wood production**	**Ecosystem services**	This provisioning ecosystem service (E.S.) is directly tied to soil quality and the market demand for goods	*added*	217	positive	Based on the chosen evaluation model	Based on the chosen evaluation model	district
	x				99	1		**Disaster defensive infrastructure**	**Emergency**	Number of facilities, systems, or measures that can be utilized for managing emergencies to withstand and respond to natural disasters (such as floods, hurricanes, wildfires, or hearthquakes)	*added*		positive	$N = \frac{D}{A}$ *N= disaster defensive infrastructure* *D = number of disaster defensive instrastructures referring to facilities, systems, or measures that can be utilized for managing emergencies* *A = surface of high risk areas*	unit/m^2	district
	x	x		x	100	0	Difficult to spatially represent	**Preservation of memory**	**Heritage**	The sum of indicators that testify the presence of documents and initiatives that preserve the memory of a disaster, such as: photographic or written archives, associations that preserve the memory of the event, cartographies or maps, community memory, traces of past measures	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing disaster memory preservation* *x = Binary variables (1 if present, 0 if no representing key elements that reflect th preservation of disaster memory* *n= total number of theelements consider*	count	district

Built Enviroment	Environmental	Social	Economic	Institutional	ID	Selection	Exclusion Criteria	Resilience indicators	Topic	Definition	N. of Sources	Source ID	Direction	Formula	Unit	Minimum territorial scale of significance
		x	x	x	101	0	Difficult to spatially represent	**Integrated Strategies for Heritage Protection, Promotion, and Innovation**	**Heritage**	The sum of indicators that testify the presence of: local incentives, community involvement and participation in the legislative process, digitalization and remote systems for assets, and a heritage digitization database	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing the presence of integrated strategies for heritage conservation, promotion and innovation* *x = binary variables (1 if present, 0 if not) representing key elements that reflect the presence of integrated strategies for heritage conservation, promotion and innovation* *n= total number of the elements considered*	count	district
x		x	x		102	0	Difficult to spatially represent	**Preservation of good practices and control of heritage**	**Heritage**	The sum of indicators that testify the presence of: best practices for conservation of landscape, territory or heritage, associations that implement these practices, cartographies or maps illustrating their application, local regulations/law supporting conservation and safeguarding actions, monitoring and alert systems	*added*		positive	$N = \sum_{k=0}^{n} x_k$ *N = total score summarizing the presence of good practices and control of heritage* *x = binary variables (1 if present, 0 if not) representing key elements that reflect the presence of good practices and control of heritage* *n= total number of the elements considered*	count	district
	x				103	1		**Land capability**	**Land use**	Land-use capability makes it possible to differentiate soils according to their productive potential in the agro-silvopastoral sphere. There are eight classes that define the capacity of soil use and they are divided into two main groupings. Classes 1, 2, 3 and 4 concern soils suitable for cultivation and other uses	*added*		to be defined	$N = \frac{K}{A}$ *N= land capability* *K= surface included in Land Capability Calsses 1 and 2 in the selected area* *A = total surface of the selected area*	%	sub-district
x	x				104	1		**Land take**	**Land use**	Total land take area, which can be expressed as an absolute measure or a relative measure, with respect to the selected area	*added*	221	negative	$N = \frac{K}{A}$ *N= land take* *K= total land take area in the selected area* *A = total surface of the selected area*	%	sub-district
x	x			x	105	1		**Urban transformation zones**	**Land use**	Surface and location of specific areas designated for redevelopment, regeneration, or significant changes in land use	*added*		to be defined	$N = \frac{K}{A}$ *N= urban transformation zones* *K= surface included in Urban transformation zones in the selected area* *A = total surface of the selected area*	%	sub-district
	x				106	1		**Ecological functionality**	**Natural/green spaces**	Amount of areas with High and Moderate Ecological Functionality, according to ecological network analysis (e.g. obtained with ENEA methodology)	*added*	218	positive	$N = \frac{K}{A}$ *N= ecological functionality* *K= surface included in the High and Moderate Ecological Functionality in the selected area* *A = total surface of the selected area*	%	sub-district
	x				107	1		**Elements of the ecological network**	**Natural/green spaces**	Amount of areas of ecological value, according to ecological network analysis (e.g. obtained with ARPA Piemonte methodology - DGR n. 52-1979 del 31/7/2015)	*added*	219	positive	$N = \frac{K}{A}$ *N= elements of the ecological network* *K= Surface included within Areas of ecological Value in the selected area* *A = total surface of the selected area*	%	sub-district
x	x				108	0	Not aligned with urban resilience-focused evaluation	**Reused water**	**Resources / Resources consumption**	Proportion of reused water as part of the total gross water consumption in a selected area	*added*		positive	$N = \frac{R}{W}$ *N = re-used water* *R= water consumption of the community in the selected area in a year, that comes from re-used water* *W = water consumption of the community in the selected area in a year*	%	urban