Mapping Urban Resilience Responses: Testing a Spatial Indicator Approach in Turin

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The complex and dynamic nature of urban resilience makes it both essential and challenging to define an appropriate qualitative-quantitative approach for its measurement that combines context-sensitive indicators with spatial analysis. The method proposed in this paper balances standardised frameworks with local specificity through the application of selected resilience indicators in the city of Turin (Italy). By spatially mapping territorial response elements related to natural vulnerabilities

Introduction

In an increasingly urbanised world (UN, 2019), cities face growing exposure to a wide range of natural and human-induced hazards, including extreme weather events, infrastructure failures, resource depletion, and socio-political uncertainty. In response to these escalating challenges, the concept of resilience has become central in both academic research and professional practice. It is now a focal point of interdisciplinary discourse across urban planning, engineering, architecture, psychology, and sociology. Although there is no single, universally accepted definition of resilience, primarily due to the varied theoretical foundations and methodological approaches of each field (Brand & Jax, 2007), *and socio-institutional dynamics, it emphasises cross-sectoral integration for effective resilience strategies for spatial planning. It further stresses the importance of developing actionable indicators capable of informing planning tools and supporting adaptive, inclusive territorial governance. These insights are useful for the ongoing revision of Turin's land use plan and other supra-local planning tools, aiming to address socio-economic and environmental challenges more cohesively.*

there is broad consensus that enhancing resilience involves integrating both physical and non-physical assets. Traditionally, particularly within engineering disciplines, resilience has been conceptualised as the capacity to resist and recover from disturbances, often with the goal of returning to a prior state. However, this static and linear interpretation fails to capture the dynamic and evolving nature of urban social-ecological systems. To address this limitation, the concept of socio-ecological resilience (Holling, 1973; Folke, 2006) emphasises resilience as the capacity to adapt and transform in response to perturbations, recognising that disturbances can alter system behaviours, potentially leading to new and different states.

When applied to urban environments, resilience must be understood in relation to the spatial, social, and institutional complexity that characterise cities. Urban areas are not only densely populated and highly connected, but they also represent dynamic systems marked by constant transformation. As such, resilience requires a tailored, context-specific approach that goes beyond conventional risk reduction or infrastructure-based strategies. According to Meerow et al. (2016), urban resilience is "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 introduces key aspects, including flexibility, adaptability, and transformative capacity, underscoring the need for responses that operate across multiple scales and systems. Building on this perspective, the necessity for a multidimensional and dynamic understanding of urban resilience arises, one that evolves alongside the changing character of urban areas and better reflects the complexity of contemporary urban systems (Kapucu et al., 2024). A more forward-looking approach recognises resilience as a transformative process (Folke, 2016) that can reposition cities to become more sustainable, inclusive, and innovative, aligning directly with the goals set out in Sustainable Development Goal 11 of

the United Nations 2030 Agenda. Consistent with this view, transformative resilience is increasingly understood as a powerful conceptual tool with the potential to reframe planning practices and interventions (Giovannini et al., 2020), shifting the focus from recovery and resistance toward proactive adaptation and long-term transformation.
In this perspective, building on this evolution from traditional to more dynamic conceptualisations of resilience, our research seeks to advance the understanding of urban resilience within the fields of urban and regional studies and planning (Davoudi et al., 2012). By critically engaging with theoretical debates and practical applications, we explore how resilience can be operationalised in planning processes and spatial strategies that address and prevent contemporary vulnerabilities and systemic risks. In particular, as the concept of urban resilience gains attention in academic and policy spheres, concerns arise about effectively evaluating and operationalising such a complex and evolving notion. The multidimensional character of resilience, encompassing physical, social, institutional, and ecological components, complicates the definition of clear, measurable indicators. Moreover, the shift from static frameworks to more dynamic, transformative perspectives calls for new approaches to evaluation that can capture long-term learning, innovation, and systemic change processes. A resilience approach, therefore, challenges traditional modes of governance grounded in predictability, controllability, and efficiency, replacing them with approaches better suited to complexity, non-linearity, and redundancy (Elmqvist, 2014). Within this context, evaluation needs to be carefully identified, not just as a technical exercise, but as a strategic act (Chmutina et al., 2023) that should shape how resilience must be understood, prioritised, and enacted in planning and governance.
Our research, developed within the framework of the RETURN project (Multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate), funded by the European Union Next-GenerationEU programme, aims to address this gap by exploring how resilience can be operatively supported through evaluation practices that are both conceptually robust and practically applicable, particularly within the context of urban planning. This endeavour requires a holistic and integrated approach that acknowledges the complexity of urban systems and their interdependent relationships and dimensions (Sharifi & Yamagata, 2016) rather than addressing each risk in isolation. Such a perspective enables a comprehensive spatial understanding that captures the multifaceted nature and dynamic processes of urban environments. Indeed, while numerous evaluation models and indicators have attempted to measure resilience, many of these tend to focus primarily on evaluating vulnerability and exposure to risks and hazards.

From this perspective, it becomes clear that resilience is not merely the inverse of vulnerability, but should instead be understood as a "set of principles to be used for the reframing and transition of an existing system" (Chelleri et al., 2015). This distinction is particularly relevant given the persistent lack of conceptual clarity and definitional consensus around urban resilience, which continues to pose challenges for developing standardised and transferable evaluation frameworks. Ultimately, the objective of our research is to identify effective planning and design strategies that can operationalise urban resilience, supported by theoretically grounded and context-sensitive evaluation methodologies.

Within this framework, we identify five interrelated dimensions through which to conceptualise resilience in urban environments: the built environment, the environmental, the social, the economic, and the institutional dimensions (Brunetta et al., 2025). These dimensions constitute the main analytical domains for evaluating the capacity of urban systems to withstand, adapt to, and recover from stresses (Ostadtaghizadeh et al., 2015). Each dimension represents a distinct but interconnected facet of urban resilience, offering a structured lens through which to design integrated responses. This multidimensional reframing highlights the need for innovative planning tools that not only address systemic interdependencies and uncertainties but also ensure the long-term provision of urban ecosystem services (Ahern, 2013; Elmqvist, 2014; Bush & Doyon, 2019). Nevertheless, despite growing academic and policy interest in resilience, the interplay between these dimensions has received limited scholarly attention.

In this regard, our research aims to address existing gaps by identifying and analysing potential interconnections and mutual influences across various dimensions of resilience and territorial risks. The primary objective is to develop a methodology capable of both monitoring progress and effectively representing urban resilience within a specific territory, thereby moving beyond vague or generic definitions. This approach is intended to support urban planning decisions and guide transformations and interventions within a more proactive, evidence-based development strategy.

To this end, the study proposes a method for spatially mapping context-specific indicators, based on the identification of territorial elements that can respond to contextual risks. The goal is to promote a more integrated and systemic approach to resilience evaluation within urban planning.

Building on this framework, the paper is structured as follows: the methodology section details the approach adopted to test a tailored set of resilience indicators through GIS-based techniques within a selected case study (Turin, Italy) in relation to specific territorial risks; the results and discussion section illustrates the main findings derived from urban resilience mapping and explores their implications for planning and evaluation; finally, the conclusion highlights key insights and reflects on the limitations encountered and potential future developments of the proposed approach.

Methodological approach

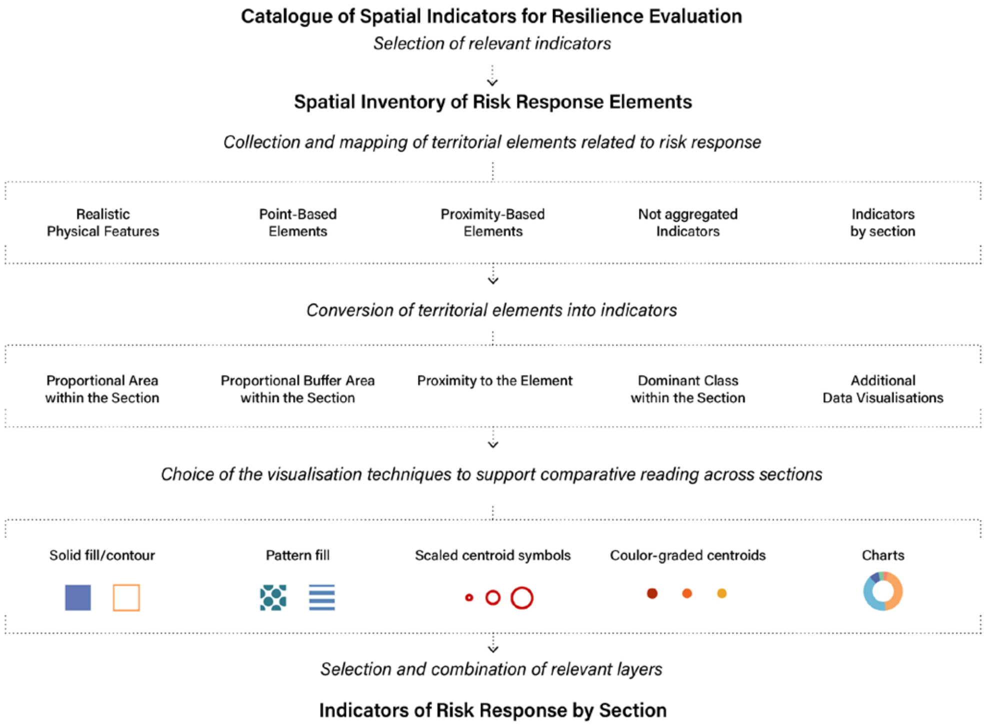
The methodology presented in this article is grounded in an extensive literature review, which informed the identification of relevant indicators for evaluating the capacity of cities and territories to respond to ongoing transformations and emerging challenges. From an initial corpus of 141 scientific papers[1], a final selection of 39 studies was conducted through systematic screening and qualitative-quantitative analysis (Cazzola et al., 2026). To ensure a comprehensive evaluation of urban resilience, this study adopts a multidimensional framework encompassing the five previously discussed dimensions of resilience: the built environment, environmental, social, economic, and institutional (Desouza & Flanery, 2013; Sharifi & Yamagata, 2016; Spaans & Waterhout, 2017; Tyler et al., 2016). The built environment dimension focuses on the physical infrastructures of cities (including buildings, transportation networks, and utilities), emphasising their capacity to withstand and recover from acute shocks such as natural hazards and infrastructure failures. The environmental dimension addresses a city's ability to mitigate and adapt to environmental risks, incorporating sustainable land use, preservation of natural ecosystems, and management of pollution to enhance resilience against climate change and other stressors. The economic dimension considers the financial stability and adaptive capacity of urban economies through diversification, job creation, and resilient business practices to withstand economic downturns. The social dimension highlights the importance of community cohesion, social equity, and inclusivity in fostering collective capacity to cope with and recover from social and economic challenges. Finally, the institutional dimension relates to governance structures, policy frameworks, and institutional capacity for coordinated crisis response and long-term resilience planning.

These selected sources provided the foundation for constructing a structured catalogue of indicators, which were categorised according to these five resilience dimensions and their associated capacities. A significant limitation observed in existing literature is the frequent reliance on generic indicators that lack precise definitions, methodological transparency, and spatial specificity. In response, our research proposes a comprehensive framework for evaluating urban resilience by developing a set of clearly defined, measurable, and spatially explicit indicators. This process resulted in the refinement and selection of 76 indicators, which form the basis of an operational tool designed to evaluate resilience across multiple urban dimensions and risks.

Given the diversity and complexity of urban settings, the adaptability of the indicator catalogue represents a fundamental requirement. Each city presents unique characteristics in terms of risk exposure, socio-economic and territorial conditions, institutional and governance structures, as well as data availability and collection capacity. Therefore, it is essential to incorporate context- and site-specific indicators that enable each city to develop a tailored framework for measuring resilience. The objective is to monitor resilience progress within the same city over time, rather than to construct cross-city rankings (Figueiredo et al., 2018). In this regard, the application of the catalogue to a specific case study is crucial, as it allows for the testing of both standardised indicators—applicable to a wide range of contexts—and customised indicators that depend on the distinctive features of a given urban environment.

To test our comprehensive framework, we identified the city of Turin (Italy) as a significant case study, given its recognised role in international urban resilience discourse[2]. Within this urban context, a segment of the Po River corridor—specifically at its confluence with the Stura di Lanzo stream—was selected as the territorial focus for testing the indicators. This area presents a particularly relevant case at many planning levels, as it is currently subject to the drafting and implementation of multiple tools, such as the Piedmont Po Park Plan (Giudice et al., 2024), and, at the metropolitan scale, the Metropolitan General Plan of Turin (*Piano Territoriale Generale Metropolitano* – PTGM), which is currently under development. These plans play a critical role in shaping resilience strategies by framing hazards and risks as key territorial components and by proposing integrated technical and regulatory responses. The Po River offers an invaluable opportunity to explore the interdependencies between urban infrastructures, natural systems, and social dynamics. In the final stage, the analysis is downscaled to the mesoscale, focusing on three neighbourhoods along the Po River, to evaluate the spatial performance of the selected indicators in a more granular territorial context (Sharifi, 2019).

From the aforementioned refined catalogue, we selected a set of resilience indicators that best reflect the specific characteristics and needs of the case study. This selection was based on the following key criteria (applied in addition to those already used to develop the whole catalogue): the availability of open spatial data at the local (sub-municipal) scale, and the relevance of each indicator in addressing the territorial risks and hazards identified within the urban context—namely hydrogeological risk, urban heat island (UHI), air pollution, and social vulnerability (further detailed in the following section). The selection process



also aimed to ensure a clear and effective spatial representation to support urban planning decisions, as discussed later in the paper.
Starting with this tailored set of resilience indicators for application to the case of Turin, we proceeded to collect a series of territorial elements identified by the research group as relevant in their capacity to address specific risks. In the initial phase, these elements were represented as spatialised vector data (linear, point based or areal, according to their original data source) and organised into simple, overlapping thematic layers. These were then reprocessed by converting them into indicators. The conversion of vector data into indicator form required the definition of a minimum spatial unit of reference. In this case, census sections (*Sezioni di censimento*) were adopted,[3] as they represent the basic statistical units defined by ISTAT (the Italian National Institute of Statistics) for all municipalities. Although designed for administrative and demographic purposes, these units are well-suited for spatial comparison across different areas according to official and standardised methods of territorial subdivisions. Different calculation methods were applied depending on the type of element: proportional area of the section, proportional buffer area, proximity measures (nearest-neighbour distance from the section centroid), or dominant class within the section. Additional data visualisations were used where required.
Once converted, the indicators were mapped through specific visualisation techniques (solid or patterned fill, scaled centroid symbols, colour-graded centroids, charts), enabling comparative reading across census sec-

Methodological flow of map processing
Source: authors' elaboration
Fig. 1

tions. Finally, the different layers were jointly visualised in resilience maps, thematically structured by risk or vulnerability type[4]. The methodological workflow for this process is illustrated in Fig. 1.

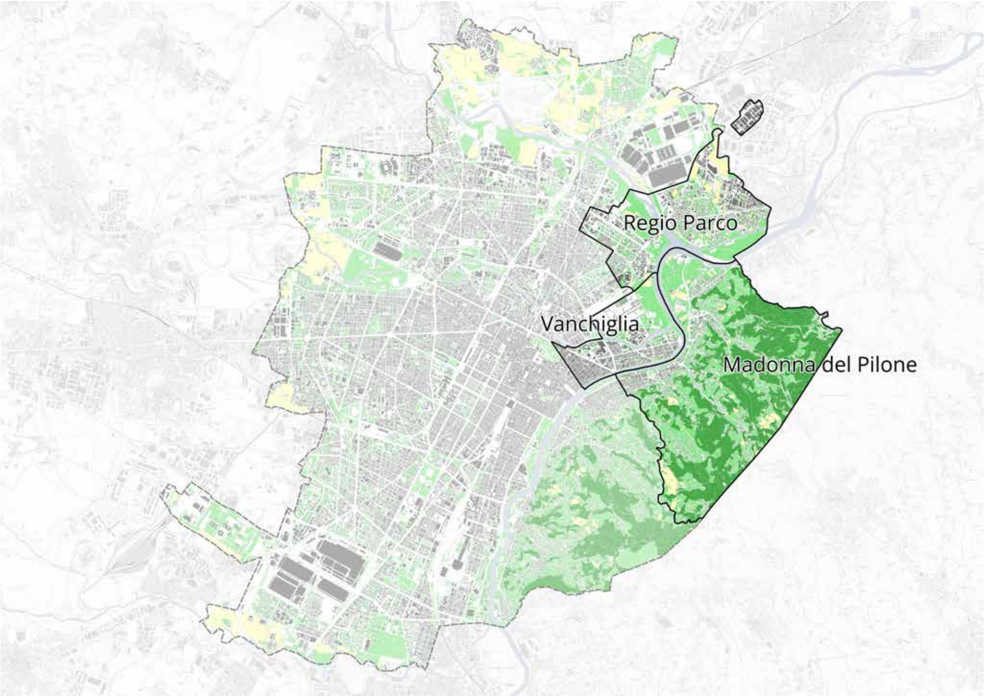
The resulting map-reading technique relied on visual overlays of multiple indicator layers based on the same spatial unit. Notably, the approach did not involve normalising or aggregating indicators into composite indices. Instead, a qualitative-quantitative method was adopted to preserve the spatial specificity of the data—an approach considered more appropriate for informing urban planning activities. The choice to avoid constructing synthetic indices reflects concerns over the limitations of purely quantitative standardisations and the need to retain a strong spatially grounded perspective to enhance territorial understanding. This representation strategy is intended to support decision-making through maps that are scientifically grounded yet accessible, making them communicable to various stakeholders. It aims to facilitate participation in urban transformations and to avoid misleading or abstract numerical simplifications, favouring more action-oriented maps.

Although the maps and indicators are initially organised by single risk types, the ultimate objective is to enable integrated, non-sectoral, multi-risk evaluations through the reasoned identification of multidimensional resilient areas or critical sites.

Testing the indicator-based approach in the city of Turin

The city of Turin is in the western part of the Po Valley, in northwestern Italy. According to the most recent demographic data, the city's population is experiencing a modest increase, with 862.999 inhabitants recorded as of December 31, 2024, compared to 860.973 in 2023. The proximity to the Alps to the west and the hilly terrain to the east encloses the city within "a complex mosaic of microclimates, with dry summers and mild wet winters" (Ellena et al., 2023). This geographical configuration also contributes to high levels of air pollution, positioning Turin among the most polluted cities in Italy and Europe (EEA, 2024). The slow transition toward sustainable mobility, coupled with a high rate of private car ownership, further aggravates this condition.

A dense built environment (which accounts for approximately 65% of the municipal territory) characterises the city of Turin (Munafò, 2024). Such a high level of imperviousness limits natural drainage and increases the city's exposure to hydrogeological hazards, particularly flooding during high-intensity rainfall events, as experienced in recent years. The extensive built-up area also exacerbates the UHI effect, thereby compounding the impacts of heat waves. Additionally, the dense urbanisation is shaped by a significant hydrographic system and hilly terrain, composed of four rivers: the Po, the Sangone, the Dora Riparia, and the



Stura di Lanzo, which together form a complex network of green corridors and protected areas (Giaimo & Vitulano, 2022).

Despite a slight increase in population, Turin continues to face structural socio-economic challenges, including an ageing population and declining birth rates. These demographic changes are further exacerbated by the long-term impacts of deindustrialisation, which have contributed to spatial and social disparities across the city. Once mainly shaped by rapid industrial growth, the city has undergone significant economic restructuring, with the decline of traditional manufacturing and automotive sectors (Armano et al., 2016) generating additional complex socio-economic vulnerabilities. Moreover, the reinvention of its post-industrial identity has allowed it to promote greenery as a core urban asset further. This has contributed to making Turin one of the greenest cities in Italy, with over 55 square meters of (public and private) green space per resident (Città di Torino, 2020a), thanks to the preservation of historic parks, the ecological recovery of river corridors, and the conversion of former industrial sites into public green areas.

In line with international and European objectives aimed at mitigating climate change and its associated impacts, the city of Turin joined the Mayors Adapt initiative in 2015 and signed up to the new Covenant of Mayors for Climate and Energy in early 2019. More recently, Turin applied to draft its Climate City Contract in 2022. These commitments are also increasingly evident in urban planning tools, as Turin is progressively adapting its instruments to address emerging societal challenges. Currently, the city of Turin is engaged in revising its municipal land use plan (*Piano Regolatore*

Territorial overview of the study area
Source: elaboration based on data from Città di Torino, 2024
Fig. 2

Generale – PRG) through an intensive process of dialogue with inhabitants and interested stakeholders. This process is expected to incorporate emerging environmental, social and economic challenges while ensuring coordination with higher-level general and sectoral plans, such as the Territorial Regional Plan (*Piano Territoriale Regionale* – PTR), the Regional Landscape Plan (*Piano Paesaggistico Regionale* – PPR), the Hydrogeological Risk Management Plan (*Piano di Assetto Idrogeologico* – PAI), metropolitan-scale plans such as the ongoing PTGM, and nature park plans such as the ongoing Piedmont Po Park Plan. Alongside these supra-local plans, Turin is supported by a range of sector-specific local planning tools, including the Urban Climate Resilience Plan (*Piano di resilienza climatica*), the Strategic Green Infrastructure Plan (*Piano strategico dell'infrastruttura verde*), and the Civil Protection Plan (*Piano di protezione civile*). In addition to their strategic and regulatory roles, these tools serve as valuable repositories of spatial data, providing robust platforms for both qualitative and quantitative analyses. This analytical potential is crucial for informing evidence-based planning and resilience strategies. Nevertheless, while these tools offer targeted objectives, they often operate in parallel rather than in synergy, which hinders their integration and the formulation of coherent, cross-cutting responses to complex urban challenges—particularly those related to urban resilience.

In this context, our research focuses on three neighbourhoods (Vanchiglia, Regio Parco, and Madonna del Pilone), located in the north-eastern sector of the city along the Po River (Fig. 2). These areas represent a complex socio-ecological system where urban, natural, and social elements intersect, making them particularly relevant for testing the proposed resilience indicators. Moreover, some major urban transformation projects are scheduled for implementation in the coming years. Notably, the planned Metro Line 2 is expected to reach some of these areas, enhancing connectivity and accessibility in zones that have historically been underserved by public transport. Some brownfield sites are planned for regeneration, including the Manifattura Tabacchi (4,5 hectares of underused land), which is intended to be redeveloped to accommodate cultural hubs and university facilities. Furthermore, the introduction of a sports centre within Meisino Park (part of the protected area of the Piedmont Po Park) will contribute to reshaping the image of this part of the city. These transformations will be complemented by several smaller-scale interventions financed through the National Recovery and Resilience Plan (NRRP).

Results and discussion

As mentioned in the methodology section, the selection of indicators derives from the need to construct a comprehensive and con-

Risk	Indicator	Resilience Dimension(s)	Data Source
Hydrogeological Risk	Dominant Class of Imperviousness	Built Environment Environmental	LCP – Land Cover Piemonte, Regione Piemonte, 2018
	Proximity to Temporary Emergency Shelters	Built Environment Social Institutional	Civil Protection Plan, Città di Torino, 2020
	Population Density	Built Environment Social	Census Sections, Città di Torino, 2024
	Percentage of Area Occupied by Brownfield Sites	Environmental	Municipal Technical Map, Città di Torino, 2024; Municipal Land Use Plan, Città di Torino, update 2024; Torino Atlas (Urban Lab), 2017
Urban Heat Island	Dominant Class of Normalized Difference Vegetation Index (NDVI)	Environmental	LCP – Land Cover Piemonte, Regione Piemonte, 2018
	Proximity to Public Water Fountains	Built Environment Institutional	I Love Toret, 2022
	Percentage of Green-Shaded Pathways	Built Environment Environmental	Municipal Technical Map. Città di Torino, 2024; Public Urban Trees (Alberate), Città di Torino), 2025
	Population Density	Built Environment Social	Census Sections, Città di Torino, 2024
	Percentage of Area Occupied by Public Services	Built Environment Institutional	Municipal Land Use Plan, Città di Torino, update 2024
Air pollution	Dominant Class of Carbon Storage and Sequestration	Environmental	Carbon Sequestration and Storage, Città Metropolitana di Torino, 2024
	Average Daily Traffic	Environmental	Regional Traffic Monitoring Graph, Regione Piemonte, 2025
	Number of Public Urban Trees	Built Environment Environmental	Public Urban Trees (Alberate), Città di Torino, 2025
	Proximity to Cycling Infrastructure	Built Environment	Territorial Coordination Plan, 2011
	Percentage of Area Occupied by Public Educational Facilities	Built Environment Social	AperTO, Città di Torino, 2011
Social vulnerability Population < 14	Aging Index	Social	Census Sections, Città di Torino, 2024
	Proximity to Urban Green Spaces	Environmental Institutional	Municipal Technical Map, Città di Torino, 2024
	Proximity to Public Educational Facilities	Built Environment Social	AperTO, Città di Torino, 2011
	Proximity to Public Sport Facilities	Built Environment Social	AperTO, Città di Torino, 2011
	Local associations*	Social	Municipal Register of Associations, Città di Torino, 2025
Social vulnerability Population > 65	Aging Index	Social	Census sections, Città di Torino, 2024
	Proximity to Urban Green Spaces	Environmental Institutional	Municipal Technical Map, Città di Torino), 2024
	Real Estate Values	Economic	Real Estate Market Zone, Osservatorio del Mercato Immobiliare, Agenzia delle Entrate, 2024
	Proximity to Hospitals	Social Institutional	AperTO, Città di Torino, 2011
	Proximity to General practitioners	Social Institutional	General Practitioners, Azienda Sanitaria Locale Città di Torino, 2025
	Income*	Economic	Socio-economic Indicator of the City of Turin, Città di Torino, 2023

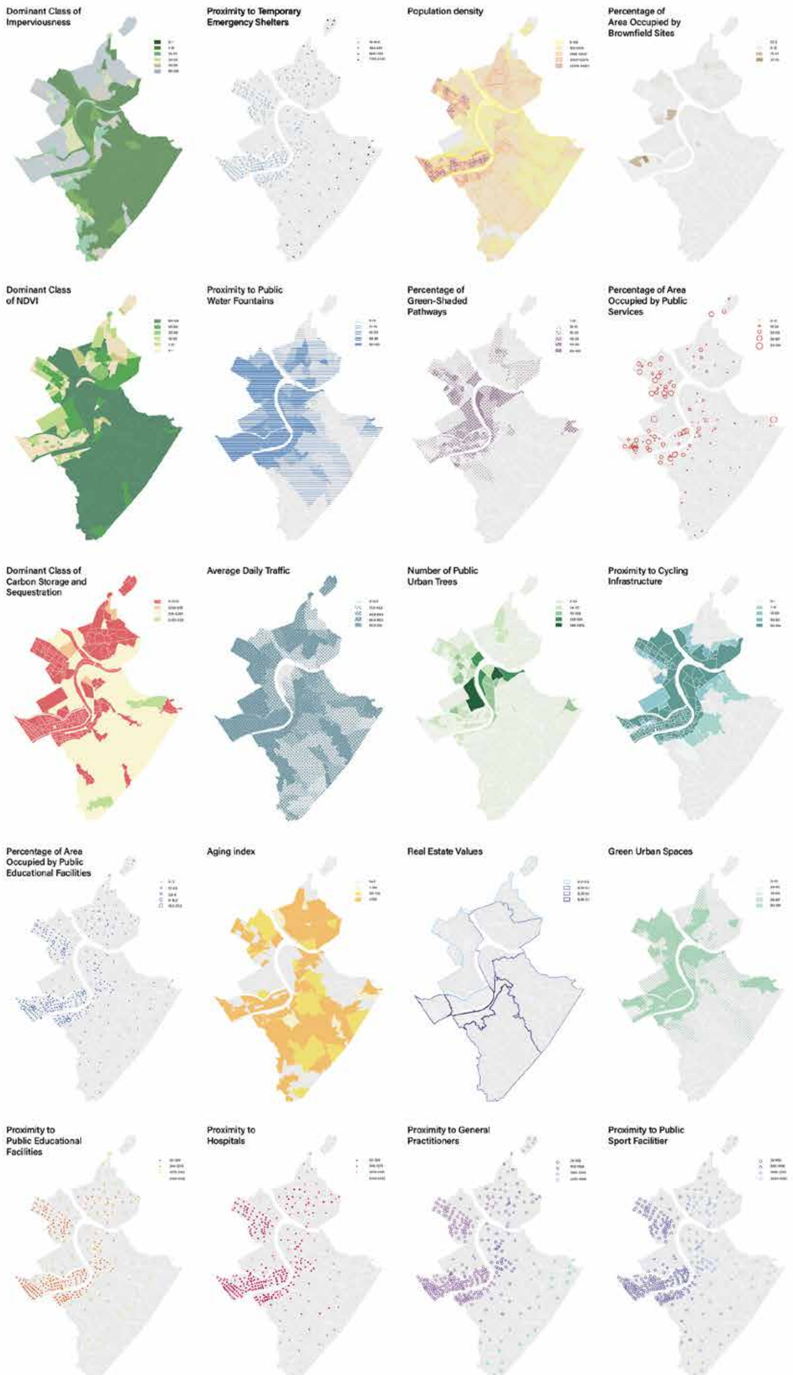
*The indicator refers to the neighbourhood scale

Overview of the selected indicators tested in the case of Turin, grouped by hazard type and urban resilience dimension, with additional details on data sources.
Tab. 1

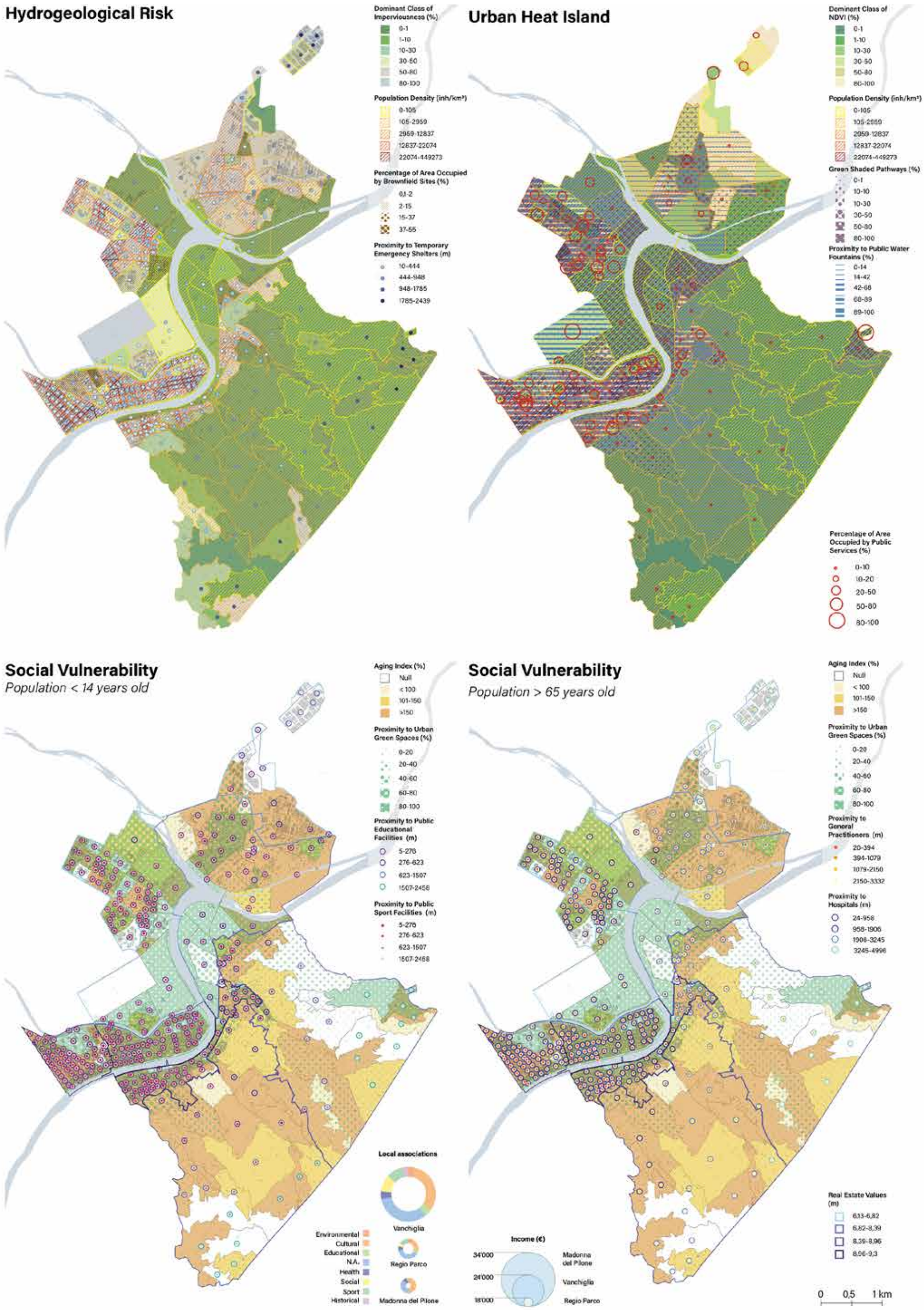
text-sensitive framework for evaluating urban resilience across multiple dimensions and risk categories. The set of indicators used in the case study reflects an approach that combines both broadly applicable indicators—suitable for different urban contexts—and place-based indicators tailored to the city of Turin. Accordingly, a core set of common and transferable indicators, such as population density, proximity to urban green spaces/hospitals/public educational facilities, and the percentage of area occupied by public services, are complemented by more localiszed indicators that may not be essential in every context for evaluating resilience. These include the ageing index, the presence of local associations, proximity to public water fountains, percentage of green-shaded pathways, and the percentage of area occupied by brownfield sites, among others.

The following table and maps illustrate how the integration of these two typologies of indicators is implemented. It is not considered necessary to set a rigid rule based on pre-defined minimum thresholds or a fixed baseline of standardiszed indicators. Instead, the method emphasiszes the importance of adapting the indicator catalogue by balancing generaliszability with local specificity, according to different nuances of vulnerabilities and adaptive capacities, to ensure effective and operational transferability of the approach to other territories. Each indicator was carefully chosen from the catalogue inventory not only for its relevance to the specific hazards identified in Turin (hydrogeological, UHI, air pollution, and social vulnerability), but also for its capacity to capture the interplay between the five dimensions of urban resilience. This multidimensional approach enables a more integrated analysis of urban resilience, considering both physical conditions and social, economic and institutional dynamics. An important additional selection criterion was the availability of open spatial data at the local scale, which particularly influenced the selection and technical refinement (calculation and visualization-visualizisation methods) of the context-based indicators. All these features are reflected in Table 1.

The maps presented in Fig. 3 display the individual resilience indicators spatially distributed across the survey area. These indicators were produced using different calculation methods, tailored to specific needs: dominant class, defined as the most frequent value class within each spatial unit; proximity, calculated either as the percentage of area within a buffer zone (typically 300 meters) around the risk response element, or by applying the nearest-neighbour GIS tool based on the centroid of the census section; and percentage, representing the share of area meeting a specific condition relative to the total census section area. Classification of values in the map legends generally follows either the natural



Map mosaic of individual selected resilience indicators spatialised across the three surveyed neighbourhoods in Turin
Source: authors' elaboration
Fig. 3



Thematic response maps displaying the spatial overlay of the selected resilience indicator

Source: authors' elaboration

Fig. 4

breaks (Jenks) method or equal intervals, depending on data distribution.
The selected resilience indicators were subsequently grouped into specific thematic response maps (Figure 4), enabling a multidimensional analysis of the study area.
Regarding the first map concerning hydrogeological risk, the multidimensional nature of urban resilience is illustrated through the combined use of indicators, such as the dominant class of imperviousness, which represents physical criticalities related to soil sealing and water runoff, and population density, which highlights the concentration of people potentially exposed to hydrogeological hazards. This relationship is particularly evident in the Vanchiglia neighbourhood, within the area bounded by the Po and Dora Riparia rivers. Here, the high share of brownfield sites in some census sections represents an opportunity for future planning interventions aimed at restoring permeable surfaces (potentially through desealing) in these highly artificial and densely populated areas. Conversely, the hilly territory, with the lowest rates of imperviousness, still requires careful considerations of responses related to hydrogeological instability and landslides, suggesting the need for further analysis focused on consolidation interventions within these areas. Instead, the indicator on proximity to temporary emergency shelters introduces the institutional dimension, as these facilities are defined by the Civil Protection Plan and represent essential infrastructure for emergency response and population safety provided by the public administration. The spatial distribution of these shelters shows a rational alignment with areas of higher population density, indicating a relatively equitable distribution in emergency planning. This reflects a proactive planning predisposition; however, it may also raise concerns about the city's adaptive capacity, especially in these peripheral areas where preparedness may be less robust.
In the case of the UHI phenomenon, the inclusion of NDVI as an environmental indicator offers a valuable measure of vegetation cover, which plays a central role in mitigating surface temperatures and enhancing microclimate regulation. Likewise, indicators such as proximity to public water fountains, percentage of green-shaded pathways, and public service availability underscore the presence and spatial distribution of climate-adaptive solutions. These elements not only represent physical mitigation responses but also align with objectives outlined in Turin's Urban Climate Resilience Plan, which focuses on relocating public fountains to more vulnerable areas, constructing shaded bike lanes, and ensuring cool and comfortable schools and public service areas (Città di Torino, 2020b). The inclusion of population density in this map also adds the importance of the social dimension, revealing the degree of exposure of in-

habitants to high temperatures. According to studies by Ellena et al. (2023), there is a high risk of UHI effects in the census sections near the Manifattura Tabacchi in the Regio Parco neighbourhood. These areas are characterised by dense population, where public services also reach significant percentages. The presence of such public spaces, together with the planned regeneration intervention of the former industrial site, represents an occasion to better qualify these areas with vegetation and shaded routes, thereby contributing to lowering temperatures, mitigating heat waves, and improving overall urban well-being. This spatial mapping thus helps identify areas where additional interventions are needed, providing the possibility to shift from simple diagnostic evaluation to proactive planning.

Social vulnerability in the study area is described through a set of demographic, socio-economic, and proximity-based indicators. To avoid overly generic evaluations, the analysis has a twofold objective, distinguishing between vulnerabilities affecting different age groups. For younger populations (under 14 years), proximity to urban green areas, public educational and sports facilities, as well as the presence of local associations, reflect not only access to essential services but also opportunities for social inclusion, physical and recreational activities, and overall quality of life. Conversely, the vulnerability of elderly populations (over 65 years) is mapped through a complementary yet distinct set of indicators, including proximity to general practitioners and hospitals, as well as real estate values, which serve as proxies for both economic and health-related accessibility. While active access to green spaces is a shared indicator between the two maps, it assumes increased relevance for elderly residents in terms of mobility support, thermal comfort during heat waves, and broader physical and mental health. The census sections of Barca and Bertolla, located on the periphery of the Regio Parco neighbourhood and the municipality, are characterised by high values of aging index and poorer proximity to hospital facilities.

Conclusions

The emerging and evolving discourse on urban resilience can benefit from integrating planning tools with evaluation methods that incorporate both qualitative and quantitative approaches. Through the development and testing of both standardised and context-sensitive indicators, this approach highlights the importance of integrating resilience thinking into both the strategic and operational dimensions of urban planning. The inherent context-dependency of resilience indicators can serve as either baselines or measures of progress (Chmutina et al., 2023). Moreover, while such indicators enable the exploration of long-term trends and system characteristics, they must be sufficiently specific and context-sensitive to inform local decision-making and planning effectively. This is particularly challenging given the dynamic nature of urban systems where resilience indicators typically measure proxy characteristics rather than performance during actual shocks. Additionally, such indicators tend to be overly broad, reducing their operational value at the local scale.

Our research addresses this challenge by proposing an integrated qualitative-quantitative approach that can be exported to different urban environments, thanks to the flexibility and adaptability of the resilience indicators catalogue. This enables a more nuanced evaluation that captures not only the measurable aspects (such as the availability of green space) but also the social and institutional factors that influence urban responses to stressors and shocks (such as the collaboration pacts). However, further steps are required to operationalise these indicators into actionable guidance that can be effectively integrated into planning instruments and decision-making processes. Indeed, while standardised frameworks offer structure and comparability, they often lack the flexibility needed to respond to local specificities. Conversely, overly localised indicators risk becoming disconnected from broader policy and planning agendas. Reconciling these tensions – between generalisation and specificity, diagnosis and action – remains one of the most pressing tasks in resilience planning. A key contribution of our research lies in addressing this tension by grounding the indicators within spatial planning processes at various scales, from regional to local levels. This once again highlights the importance of scale in resilience planning. As Elmqvist (2014) suggests, transformations at smaller scales are often necessary to sustain resilience at the urban or regional level. In our case, the downscaling of indicators within the Po River corridor in Turin demonstrates how localised evaluations can reveal spatial disparities and support targeted interventions, while still contributing to broader urban resilience goals.

One of the most pressing challenges we need to address is ensuring that these resilience indicators are not merely diagnostic tools but are also meaningful and actionable for policy and practice. Addressing this issue requires future efforts to go beyond the technical refinement of indicator sets and focus on strengthening institutional capacity to interpret, integrate, and act upon them in a coherent, inclusive, and adaptive manner over time. In the case of Turin, this challenge is compounded by the fragmentation of existing planning tools. While the city has developed a range of sectoral and thematic plans (the Urban Climate Resilience Plan, the Strategic Green Infrastructure Plan, and the Civil Protection Plan), these instruments often operate in isolation. The lack of coordination between them hinders the development of integrated strategies that can address the multifaceted nature of urban resilience. Embedding a unified indicator framework across these tools can offer a promising pathway to promote consistency, facilitate cross-sectoral dialogue, and enhance the city's capacity to respond adaptively to future challenges.

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Attributions

The article is the result of a joint reflection by the four authors. However, the "Introduction" section is attributed to BG; the "Methodological approach" section to IC; the "Testing the indicator-based approach in the city of Turin" section to VV; the "Results and discussion" section to IC, MR, and VV; and the "Conclusions" section to BG.

Notes

[1] The selection process was initially based on systematic queries of the Scopus database. It was subsequently expanded to include grey literature, institutional reports, and databases, thereby ensuring a more comprehensive coverage of resilience evaluation practices.

[2] In recent years, the city of Turin has actively participated in several European Union-funded projects (such as the H2020 projects CONEXUS and proGIreg, as well as CLIMABOROUGH within the '100 Climate Neutral and Smart Cities' Mission), focusing on climate change, green infrastructure, and the development of adaptive strategies to address ongoing urban challenges.

[3] Data source: 2024, Città di Torino.

[4] All analyses were primarily carried out using GIS software (QGIS version 3.40.6)

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