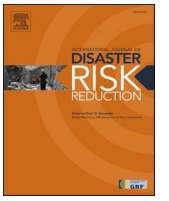
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Human dimensions of vulnerability, resilience and adaptive capacity: A scoping review of concepts and indicators

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ABSTRACT

As built environments confront intensifying climate threats, the human capacity to adapt emerges as a critical determinant of resilience increase and vulnerability reduction. However, these human dimensions remain fragmented across disciplines such as psychology, disaster management, engineering, and socio-ecology, often overshadowed by infrastructural or environmental metrics due to conceptual overlaps and inconsistencies. To address this gap, this scoping review synthesizes evidence from 81 included articles to focus exclusively on human-centered aspects, mapping definitions, indicators, and interrelations of human vulnerability, resilience, and adaptive capacity, while identifying gaps and avenues for evidence-based adaptation practices. The findings indicate a shift from static, hazard-focused vulnerability models to dynamic integrations of psycho-social drivers such as risk perception and social capital. Resilience, in turn, emerges as process-oriented recovery mechanisms, while adaptive capacity bridges the two concepts through proactive resources, drawing on shared indicators across social, psychological, and physiological domains. Persistent gaps nevertheless remain, including ambiguous conceptual boundaries, overlooked behavioral influences, and the lack of standardized, longitudinal measurements. These patterns frame adaptive capacity as a unifying thread and lay the foundation for a novel multidimensional research agenda that integrates physiological, psychological, behavioral, and social dimensions to assess human adaptive capacity in built environments more systematically. This work thereby invites a rethinking of how adaptation research conceptualizes people, not as passive recipients of risk, but as active agents embedded within dynamic physical and social settings.

1. Introduction

Climate change leads to an increased frequency, intensity, and duration of extreme weather events, which pose significant threats to human health and well-being [1,2]. Although the built environment shields humans from adverse climatic conditions, this protection does not automatically translate into human resilience. A human may need to be able to adapt to both indoor and outdoor conditions. Such adaptation necessitates proactive human responses, where individuals and communities actively mitigate risks rather than passively endure increasingly unpredictable changes, transforming vulnerabilities into resilient pathways and promoting

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sustainable development [3]. Addressing the long-term effects of fostering human resilience is equally critical to managing immediate risks, as repeated exposure to mild stressors, compared with avoiding stressors, can build adaptive capacities over time, leading to improved health outcomes and reducing reliance on energy-intensive technologies [3,4].

In this review, the human dimension refers to the human system as a whole, from physiological and psychological characteristics through behavior to social aspects, and how the human system interacts with the environment and responds to stress. Because human system is inherently complex, dynamic and non-linear [5], vulnerability, resilience and adaptive capacity are therefore treated as properties of the human system rather than of the individual alone [6]. The human dimension is particularly important in vulnerability, resilience and adaptive capacity research because social capital, behavioral adaptations, and psychological coping mechanisms interact with physical structures to determine adaptation effectiveness [7,8]. However, defining and assessing these concepts faces challenges due to fragmentation across disciplines in both terminology and assessment approaches [9], including built environment studies, psychology, disaster risk management, engineering, and socio-ecology, leading to inconsistent interpretations and limited interdisciplinary approaches.

The concepts of human adaptive capacity, resilience, and vulnerability show considerable overlap and inconsistencies, often resulting in conceptual ambiguity; for example, resilience is sometimes framed as the inverse of vulnerability [10], while adaptive capacity is more often treated as a related capacity shaping both [9,11]. Whether this conceptual ambiguity exists at the level of measurement, and if so, to what extent, is one of the questions addressed in this review. Yet, definitions vary widely across studies [12], which complicates their application in built environments. While vulnerability may emphasize exposure and sensitivity [11,13], resilience often focuses on recovery and maintenance of function [14–16], and adaptive capacity typically stresses proactive adjustments through resources and learning [17,18], these emphases still overlap in how studies operationalize these concepts. Additionally, current literature reveals key gaps: many models concentrate on specific dimensions, such as social factors [7,19–22] or biophysical elements [23,24], but they overlook the holistic, multidimensional nature of adaptation, particularly the integration of human agency, perception, and social interactions within built-environment systems. For instance, occupants' adaptive behaviors are often neglected: in one review, authors found that 12 out of 22 studies treated people as passive loads with no adaptive behavior, and thereby ignoring their role in resilience strategies [25]. Similarly, Yu et al. [26] developed geospatial indicators to assess adaptive capacity but acknowledged omitting critical human factors like health, housing quality, and social support, thereby highlighting the limitations of their approach in capturing the full spectrum of human adaptation [26]. This siloed approach not only overlooks the synergistic interactions among these concepts but also fails to address how built environments facilitate or constrain human vulnerabilities in climate variability, while pointing to a lack of standardized human indicators, underscoring the need for more integrated, human-centered inquiries.

Existing well-established reviews have shaped the conceptual foundations of vulnerability, resilience, and adaptive capacity [9,11,27,28], explaining why the three concepts are linked. However, conceptual linkage does not show which indicators are actually used to operationalize each concept in current empirical practice or how consistently they are used across disciplines, hazards, and time periods. An updated empirical synthesis is therefore needed to systematically map how these concepts are measured in interdisciplinary research and to understand how distinct their indicators are in practice.

To bridge these gaps, this scoping review systematically maps and synthesizes interdisciplinary literature examining concepts of human adaptive capacity, resilience, and vulnerability in the built environment field in the context of climate change and climate-

Table 1
Search engines, string, and screening criteria.

Search Engines	Web of Science, PubMed, Scopus
Search String	("adaptive capacity' OR resilience OR coping* OR adaptat* OR vulnerability) AND (human OR people OR individual* OR communit* OR population) AND ("built environment' OR architecture OR urban OR city OR cities OR town* OR neighborhood*) AND (Indicator* OR dimension* OR exposure* OR measure* OR metric* OR index* OR assessment* OR sensitivity OR "environmental stressor*" OR stressor* OR hazard* OR risk* OR "climate change")
Screening Criteria	**Title & Abstract Inclusion** ■ English language. ■ Non-plant or animal related. ■ Peer-reviewed, non-conference proceeding, review articles. ■ With title or abstract including at least one of the following words: adaptive capacity, resilience, coping capacity, coping ability, adaptation, vulnerability. ■ Explicit focus on human populations (individuals, communities, or groups) within built or urban environments. ■ Focus on measure, assess, or evaluate specific indicators of adaptive capacity, resilience, or vulnerability. **Title & Abstract Exclusion** ■ Papers are not aligned with the topics specified in the inclusion criteria. ■ The abstracts indicate that the paper is a book, conference paper, a study proposal and so on. **Full Text Inclusion** ■ Explicit assessment of human adaptive capacity, resilience, or vulnerability (and/or their indicators). **Full Text Exclusion** ■ Full text not retrievable. ■ Focus solely on built environment, physical infrastructure, or policies without linking them to human-centered indicators. ■ Focus exclusively on psychological, social or personal life stressors unrelated to environmental, climatic, or disaster-related hazards. ■ Lacks relevant data or does not specifically address the "human adaptive capacity, resilience, or vulnerability concepts' as outlined in the search strategy.

related hazards. The aims are to explore the definitions and interrelations among these concepts, identify measurement indicators, uncover gaps and inconsistencies, and propose a multidimensional research agenda for human adaptive capacity to inform climate-resilient practices. Guiding the review are the following research questions: (RQ1) How are human vulnerability, resilience, and adaptive capacity conceptualized in research related to built environments? (RQ2) What indicators quantify these human-centered notions? (RQ3) To what extent do the indicators used for these concepts overlap or differ across studies? (RQ4) And what gaps persist, necessitating refined frameworks for future adaptation?

2. Methods

2.1. Search strategy & study selection

This scoping literature review followed the PRISMA extension guidelines for scoping reviews [29]. The *a priori* protocol can be

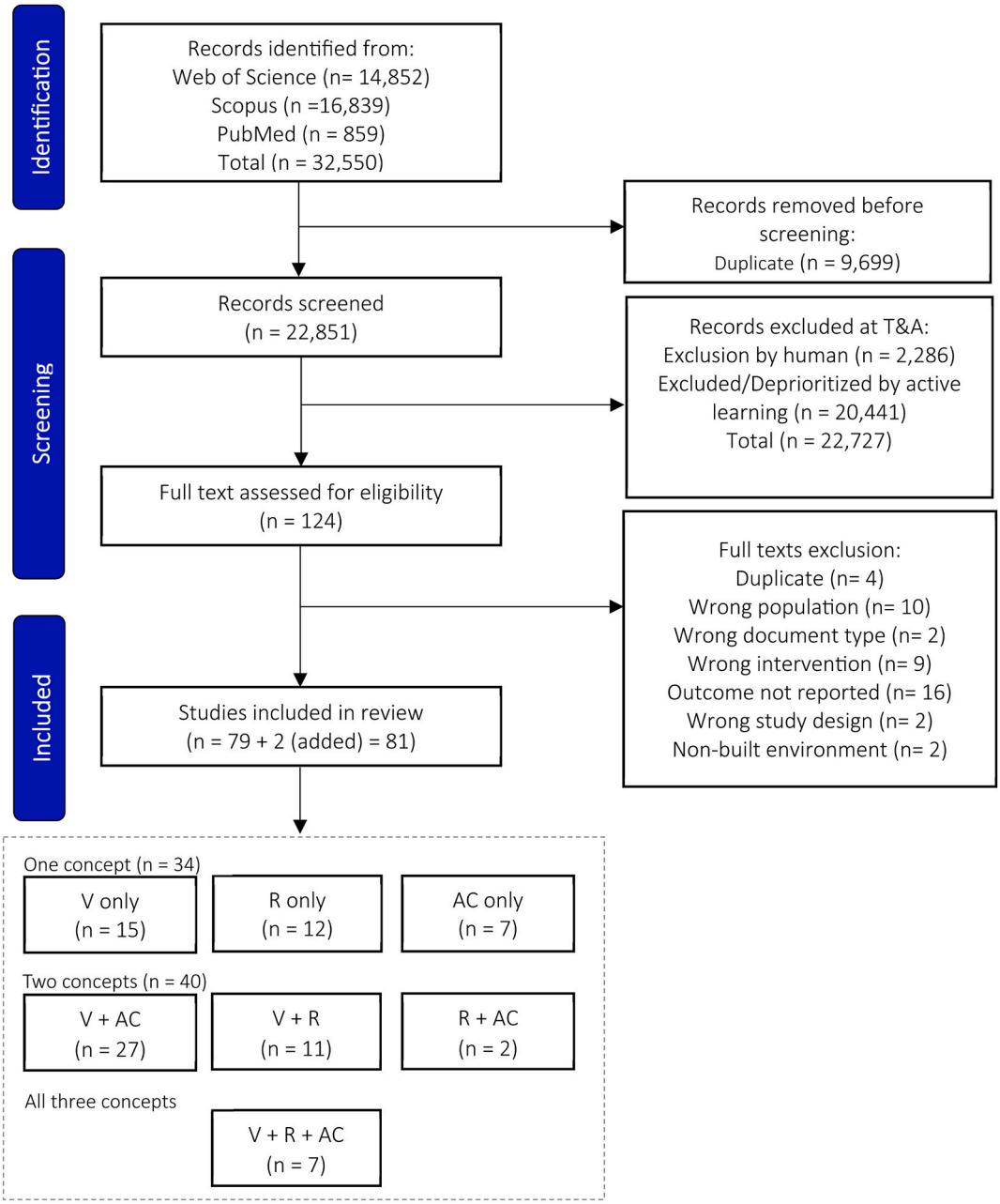


Fig. 1. PRISMA flow diagram. V = Vulnerability, R = Resilience, AC = Adaptive Capacity.

found at OSF (osf.io/jskwd). The literature search was performed in March 2025 across three databases: Web of Science, PubMed, and Scopus, which provide good coverage of articles in environmental science, social science, architecture, and public health. The search string integrated terms for the key concepts (adaptive capacity, resilience, vulnerability), human elements, built environment contexts, and measurement aspects (Table 1). Publications were limited to peer-reviewed journal articles published in English between 2000 and 2025 to focus on recent developments in the field while also capturing their evolution alongside rising climate change concerns. The returned literature was iteratively screened for relevance against set inclusion criteria (Table 1). Eligibility was assessed at the level of human systems rather than individual characteristics alone, consistent with the human dimension as defined in this review. Articles were retained if they clearly focused on human populations (individuals, communities, or groups) within built environments and addressed indicators or measurements of adaptive capacity, resilience, or vulnerability in relation to environmental, climatic, or disaster-related hazards. Studies centered on plants, animals, infrastructure, or non-environmental stressors without linking them to human adaptive capacity, resilience, or vulnerability were excluded. Following PRISMA 2020 [30] and PRISMA-ScR, individual reasons for exclusion are recorded at the full-text stage (Fig. 1).

Full texts of the remaining articles were then retrieved and screened for fit against a second set of more comprehensive inclusion criteria (Table 1). In addition to database searching, backward snowballing was conducted by screening the reference lists of all included full-text articles to identify additional relevant studies. Studies identified through snowballing were assessed using the same eligibility criteria and screening procedures as those retrieved from the database search. EndNote software was used to manage references and remove duplicates. Title and abstract screening were performed with the support of ASReview LAB version 2.1.1 (https://asreview.nl/, [31]), an open-source tool that applies active learning to prioritize records for human review. It ranks records by predicted relevance and updates this ranking after each human decision. Every inclusion and exclusion decision reported in this review was made by a human reviewer against the criteria in Table 1. Screening used the ELAS u4 learner, with prior knowledge of six included and five excluded records.

Screening continued until three complementary stopping criteria were met: (1) estimated recall reached 99%, (2) more than 10% of the total dataset had been screened, and (3) the last 500 consecutively reviewed records were all marked irrelevant. Recall was estimated by screening an independent random sample of records from the screening dataset and scaling the proportion found relevant to the full dataset. All three criteria were met after 2410 records (10.5%) had been reviewed, leaving 20,441 records not manually reviewed; no relevant records were found in the last 519 consecutive records. The threshold of 500 consecutive irrelevant records is conservative: Ros et al. [32] propose 50, while thresholds in published reviews range from 20 to 500 [33]. Because the reliability of these criteria depends on the dataset and model [34], and because the recall estimate is approximate, the criteria were treated as convergent evidence rather than proof. Together, these criteria make it unlikely, though not impossible, that any important study remained unscreened.

2.2. Data extraction & synthesis

Extracted items included study identifiers (authors, title, publication year, DOI), objectives, study type, context, exposure (e.g.,

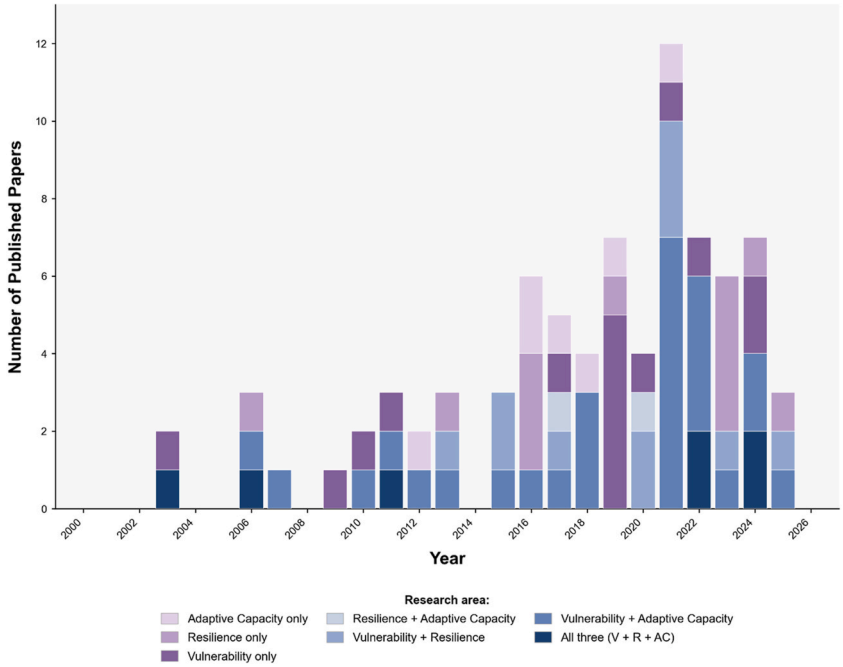


Fig. 2. Number of published papers per year and per research area.

climatic hazards), sample characteristics (type and size), research area, definitions of vulnerability, resilience, and adaptive capacity, listed indicators, and key findings. These items were selected to directly address the research questions: definitions and conceptual descriptions addressed questions (1) and (3); indicators and related findings addressed question (2); and study characteristics (e.g., study type, context, exposure, and research area) and key findings supported the identification of gaps and inconsistencies and informed the proposed research agenda in question (4). Synthesis was narrative and thematic. Definitions were mapped across disciplines, and indicators were clustered into categories. Concept categories were not exclusive and papers addressing more than one concept were counted under each. A concept was coded as operationalized where at least one indicator, variable, index, component, or other measurable proxy was reported, and as conceptually referenced where it was only defined, without being measured. Indicators were extracted and assigned to dimensions as reported in the source studies. Indicators reported for a sub-dimension were assigned to both the sub-dimension and the overarching concept, and those reported only at the overarching level were assigned there alone unless the paper specified otherwise. We recorded two scales: the scale at which indicators were measured, and the scale at which conclusions were stated. Three levels were used: individual, household, and community. Population groups were treated as sample characteristics, not as a separate scale. Hazard categories were not exclusive, and papers reporting more than one hazard were counted under each. Papers describing exposure only in general terms were assigned to a separate category and excluded from the hazard-specific counts. Temporal trends were examined across time periods to illustrate conceptual and indicator evolution. Visual summaries (Figs. 2–6) supported the presentation of publication patterns, indicator shifts, and the proposed multidimensional research agenda.

3. Results

A total of n = 32,550 records were identified through the search engines, and n = 9699 duplicate records were automatically removed before the abstract screening. After the initial screening phases, n = 124 records were selected for full-text review. A total of n = 81 papers were finally considered for the review, among them two additional studies identified through snowballing that met the eligibility criteria. A 100% inter-reviewer agreement was reached among the three reviewers at the end of the screening process. Fig. 1 shows the entire process of identification, screening, eligibility, and inclusion, as well as the number of articles included/excluded in each step.

The final n = 81 articles were divided into the three core concepts of interest according to their focus. Articles were counted under each concept they addressed, so concept totals exceed the number of articles. Vulnerability was addressed in n = 60 studies, including n = 54 that operationalized it, and n = 6 that only referenced it without indicators. Resilience was addressed in n = 32 studies, of which n = 24 operationalized it and n = 8 referenced definitionally only. Adaptive capacity was addressed in n = 43, operationalized through

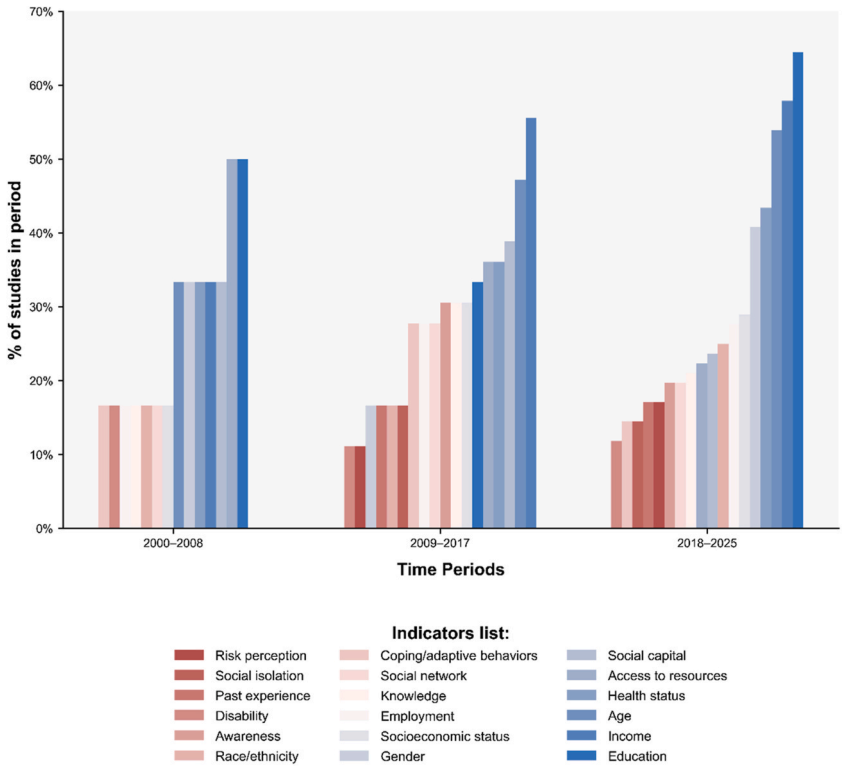


Fig. 3. Distribution of combined indicator sets for human vulnerability, resilience, and adaptive capacity across three time periods (2000–2008; 2009–2017; 2018–2025). Bars show the percentage of studies in each period that reported each indicator.

indicators in n = 40, and conceptually defined only in n = 3.

Overlap between the three concepts was common. N = 34 studies addressed one concept only (vulnerability n = 15, resilience n = 12, adaptive capacity n = 7), n = 40 addressed two, and n = 7 addressed all three concepts. The most common combination was vulnerability and adaptive capacity (n = 27), followed by vulnerability and resilience (n = 11); while resilience and adaptive capacity occurred together in only n = 2 studies. Including the three-concept studies, vulnerability and adaptive capacity co-occurred in n = 34 studies, vulnerability and resilience in n = 18, and resilience and adaptive capacity in n = 9. Detailed characteristics of all 81 studies, including specific concepts addressed, geographic context, hazards examined, indicators and definitions used, are provided in Supplementary material.

Fig. 2 shows the temporal distribution of n = 81 included studies, indicating a steady and continued increase in articles published over time. From 2000 to 2015, publications were sparse and predominantly focused on vulnerability. After 2016, publication activity expanded dramatically, driven by growing attention to adaptive capacity and resilience alongside continued work on vulnerability. This rise coincides with major international milestones (e.g., the Paris Agreement [35], IPCC special reports [2], and extreme weather events), suggesting a paradigm shift from a primarily risk-oriented perspective toward a more forward-looking approach that emphasizes the capacities and processes enabling people and communities to anticipate, absorb, and transform in the face of climate hazards within built-environment contexts.

Geographically, the literature was most concentrated in Asia, followed by North America, global context, Africa, Australia, Europe and South America. In terms of exposures, the reviewed papers emphasized a range of environmental hazards, with heatwaves leading (36 papers), followed by floods (34 papers), storms and hurricanes (9 papers), droughts (6 papers), earthquakes (7 papers), and wildfires (5 papers). Because many studies named several hazards, these count to more than 81. Furthermore, 42 papers examined a single hazard, while 25 examined two or more. The remaining 14 papers name no specific hazard, and describe exposure in general terms such as climatic stressors, environmental hazards or disaster risk. These 14 are reported separately and are not included in the hazard counts above. Methodologically, quantitative methods were the predominant study type, including survey-based and cross-sectional designs, indicator- and index-based assessments, and spatial- or secondary-data analyses. These were followed by mixed-methods approaches, which combined surveys with interviews, focus groups, stakeholder discussions, and field observations. The remaining papers included qualitative studies (e.g., interviews, narrative/thematic analyses, and case-study approaches), and conceptual studies (e.g., theoretical and methodological framework papers and literature reviews).

Measurement and inference scales differed across many studies (Supplementary Table 1). Indicators were measured at individual level in n = 37 studies, at household level in n = 28 and at community level in n = 39. Totals exceed 81 because some studies measured at more than one level. Conclusions were stated at community level in n = 66 studies, at individual level in n = 20, at household level in n = 13 and at national level in n = 1. Conclusions matched the measurement scale in 50 studies (61.7%). In n = 31 studies (38.3%), conclusions were stated at a higher level than the data measured, of these, n = 16 measured individuals only, n = 9 households only, n = 5 measured both, and n = 1 combined individual and community data to support a national claim. No study inferred individual-level conclusions from community data alone. Two studies linked community characteristics to individual outcomes using multilevel models. Among the 31 upward-inferring studies, only 8 reported an aggregation rule. Another 8 measured and concluded both at community level, but used person-level variable names for area-level data.

Extraction and synthesis identified 58 indicator groups across the three concepts. Of these, 33 (57%) were used for all three concepts, 18 (31%) for two, and 7 (12%) for one; thus, 51 of 58 groups (88%) were used for more than one concept. Pairwise, vulnerability and adaptive capacity shared 40 groups, resilience and adaptive capacity shared 40, and vulnerability and resilience shared 37. Additionally, the shared groups accounted for most measurement. The 33 groups used for all three concepts represented 86% of vulnerability, 82% of adaptive capacity, and 77% of resilience indicator mentions. These included age, income, education, health status, gender, socioeconomic status, employment, access to resources, social capital, social networks, and knowledge and awareness. Concept-exclusive groups accounted for only 0.2%, 1.7%, and 4.2% of mentions for vulnerability, adaptive capacity, and resilience, respectively. Differences between the concepts therefore reflected the relative weight given to shared indicators rather than the indicators used. Vulnerability emphasized demographic and structural attributes, with age, employment, and race/ethnicity appearing more frequently. Adaptive capacity placed greater weight on capacity and cognitive attributes, including social capital, knowledge, and self-efficacy. Resilience placed greater emphasis on relational attributes, particularly social support. Vulnerability measurement was also the most standardized, with its ten most frequently used groups accounting for 59% of indicator mentions, compared with 49% for adaptive capacity and 46% for resilience.

For temporal comparison, the included studies were grouped into three comparable time periods based on publication year (2000–2008, 2009–2017, and 2018–2025). This time grouping supported a structured comparison of how concepts and indicators evolved over time, including changes in the frequency and diversity of indicators across the literature.

Fig. 3 presents the distribution of human vulnerability, resilience, and adaptive capacity indicators across three time periods. Because the number of studies varies between periods, frequency is reported as percentage rather than counts. The figure displays how often these key indicators appear in the literature within each period. Less frequently reported indicators (e.g., those mentioned only once or twice) are not shown in this overview.

Overall, the figure shows two key patterns. First, the range of indicators widened as new variables such as awareness, past experience, risk perception and social isolation appeared in later studies. Second, while earlier studies relied more on socio-demographic indicators (e.g., race and ethnicity, income, age), later studies incorporated a broader range of social, economic, and capacity-oriented dimensions. Education remained one of the most frequently reported indicators, followed by income and age. This overview serves as an entry point to the more detailed analyses presented in the following sections. The subsequent subsections explore how these indicators are framed within each of the three concepts of human vulnerability, resilience, and adaptive capacity separately.

3.1. Human vulnerability

Human vulnerability emerged as the most prevalent concept across the reviewed studies (n = 60), pointing to its fundamental role in understanding how climate hazards disproportionately affect individuals and communities. The concept of vulnerability is conceptualized as a pre-existing human condition and a predisposition to harm caused by overlapping social, economic, demographic, and institutional factors that limit individuals' or communities' ability to anticipate, withstand, or recover from climatic stressors (see Supplementary Table 1 for all contributing studies; e.g., Ref. [23,36–43]). Definitions of vulnerability consistently framed it as a function of three interacting components: exposure (the degree and duration to which people are exposed to the hazard), sensitivity (the degree to which individuals or groups are affected by the hazard), and adaptive capacity (the ability to adjust or recover) often acting as a mitigating factor (Vulnerability = Exposure + Sensitivity – Adaptive Capacity) [13,26,42,44]. This perspective presents vulnerability as a pre-event state, distinguishing it from actual damage outcomes [9,45]. However, as discussed below, this static framing is not the only definition, and more recent studies increasingly treat vulnerability as dynamic rather than fixed.

Across disciplines, definitions of human vulnerability differ but share a core idea: it measures the potential for "future harm" [9,22,37]. In early geography and political ecology work (2000s–early 2010s), vulnerability was framed as a result of social inequalities, emphasizing structural factors like poverty and racial marginalization that place ethnic minorities or the urban poor in high-exposure zones [37,43,45]. By the mid-2010s, public health and epidemiology perspectives introduced dynamic elements like physiological sensitivity (e.g., pre-existing conditions) and behavioral responses, with a focus on measurable health outcomes [46–48]. Recent studies (2020s) in urban planning and socio-ecological fields show that vulnerability is dynamic and influenced by context, policy changes, and evolving through learning from repeated events [42,44,49,50]. This shift from static social deficits to dynamic, psycho-social views suggests that definitions are becoming more inclusive of human-centered dimensions.

Some debates focus on vulnerability versus risk, with implications for human-centered policies. While vulnerability is the potential to harm or loss [49], risk, as defined by the IPCC [2,2], refers to the chance that a harmful event will occur and cause impacts, based on the interaction between a hazard, the people or systems exposed to it, and their underlying vulnerabilities (Risk = hazard + exposure + vulnerability). Vulnerability also overlaps with concepts like resilience and adaptive capacity through shared human factors such as social capital, yet its focus on deficits differs from their focus on assets and strengths. Thus, resilience and adaptive capacity are inverses of, or complements to, vulnerability. However, at indicator level, this framing is not matched by distinct measurement: 33 of 58 indicator groups are used for all three concepts and 51 of 58 for more than one. Integrated approaches are needed to avoid conceptual silos [9,17,36].

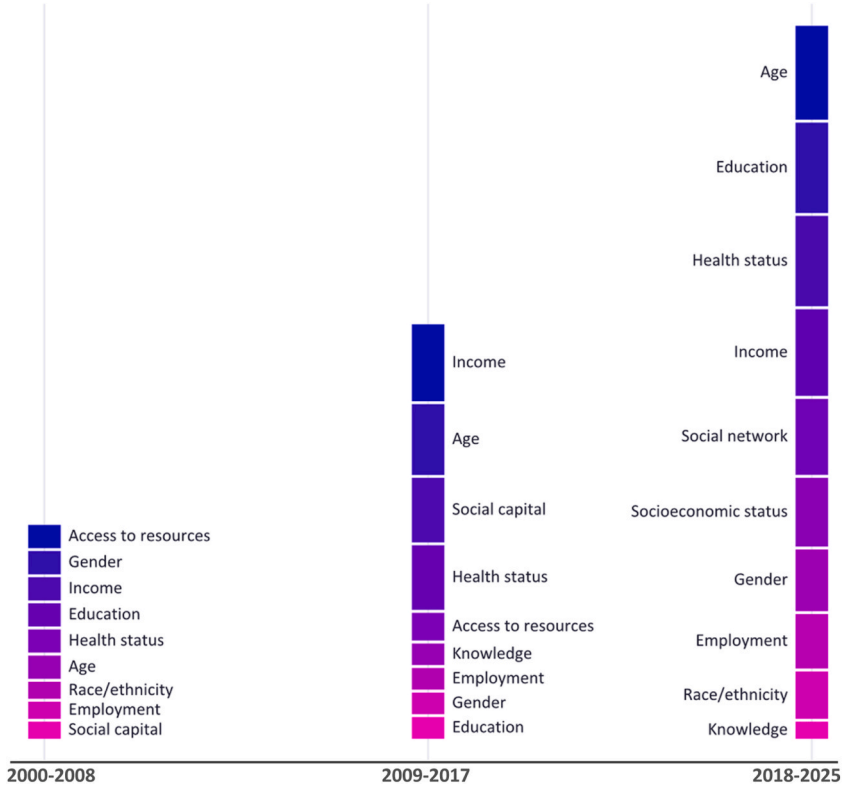


Fig. 4. Thematic evolution of human vulnerability indicators across time. Each segment represents an indicator, with height showing the share of studies using it, ranked by frequency.

3.1.1. Measurement and indicators

Across the 60 reviewed papers on human vulnerability, 54 operationalized it through indicators. Age emerges as the most repeated indicator, appearing in 41 of the 54 studies (76%), followed closely by income (36 papers) and social capital (35 papers, defined variably across studies, most commonly through social networks, trust, support, and isolation). Education (32 papers), health status/pre-existing conditions (28 papers), gender (24 papers), employment (21 papers), socioeconomic status (19 papers), race/ethnicity (18 papers) and access to resources (17 papers) constitute a second tier of highly recurrent indicators. Less frequent but increasingly prominent variables include language barriers (10 papers), knowledge and awareness (9 papers each), and risk perception (8 papers).

Temporal trends in human vulnerability indicators are described as shares of studies within each period, since the number of studies increases substantially across periods. In the early 2000-2008, indicators were largely limited to basic demographics and access to resources, suggesting the influence of early social vulnerability indices such as Cutter's Social Vulnerability Index (SoVI) [37]. Between 2009 and 2017, income, social capital, and health status gained prominence alongside continued emphasis on age and emerging attention to knowledge, awareness, and risk perception (e.g., Ref. [47,48]). From 2018 to 2025, focus on education, socioeconomic status, social networks, and gender suggest a growing emphasis on structural inequality and psycho-social understandings of vulnerability (e.g., Ref. [42,50,51]). Age and income are used consistently across all periods (Fig. 4).

The human vulnerability indicators can be clustered into three main categories of physiological, psychological, and social dimensions as follows.

- Physiological Indicators: age (e.g., older population, children), gender, health and pre-existing conditions (e.g., disabilities, cardiovascular, respiratory).
- Psychological Indicators: disaster awareness, risk perception, knowledge, prior experiences, beliefs, spirituality, cultural practices, skills, mental health.
- Behavioral Indicators: coping strategies.
- Social Indicators: socioeconomic status, income, social capital, education, employment status, minorities, access to resources.

Vulnerability studies were primarily reporting socio-demographic, psychosocial, and resource-related indicators. The findings show that socioeconomic status, age, and education explain the largest share of spatial and interpersonal variation in vulnerability scores. Although the studies used different measures and scoring approaches, the reported direction was generally similar: lower socioeconomic status, older age and younger age (particularly children), and lower educational attainment were associated with higher vulnerability [47,52–54]. However, recent studies increasingly caution that these variables can mask important nuances: high income does not automatically result in low vulnerability if risk perception or institutional trust is weak [42], and strong bonding social capital can sometimes reinforce risk denial rather than reduce vulnerability [22,55]. Wolf et al. [22,22] showed that strong bonding networks among older UK residents increased heatwave vulnerability by reinforcing denial and coping illusion that “heat is not a threat to us”, confusion between UV and heat risks, and narratives of independence that discouraged help-seeking [56]. Meanwhile, positive relational resources, trust, collective efficacy, and place attachment emerge as protective in Guangdong [57], and coastal Indonesia [58]. These findings reflect that human vulnerability is not only about who people are and what they lack, but also how they perceive risk and interact within their social networks.

3.2. Human resilience

The term resilience derives from the Latin word resiliō, meaning “to bounce back” [59,60]. However, the concept has since evolved, beyond merely returning to the original state, to a capacity not just to rebound, but to adapt, learn, and sometimes fundamentally transform in the face of disturbance [61].

Resilience first appeared in engineering and mechanics in 1858 with meaning of rapid recovery to a single stable equilibrium, focusing on efficiency, constancy, and rapid jump-back. This "engineering resilience' prioritizes resisting change to conserve existing structures [3,27,57]. Alexander [59], however, traces the earlier mechanical meaning of resilience to the capacity of materials to both resist force through strength and absorb it through deformation, highlighting the combination of resistance and ductility. By the 1970s, psychology reframed it as an individual's ability to cope with adversity, or thrive despite challenges (Garmezy and Streitman 1974 cited in Ref. [5]). In ecology, Holling (1973), redefined resilience as the ability of a system to absorb disturbance and still maintain its core functions without undergoing to a different state (cited in Ref. [3,27,60,62]). Unlike the engineering resilience approach, which assumes a single equilibrium, the ecological resilience considers multiple equilibria, and after a shock, the system can either return to the pre-shock state or move on to another state [18].

From the 1990s onward, definitions expanded to include social dimensions, coping with shocks from social, political, and environmental disturbances [27,60,63]. By the 2000s, social-ecological resilience explicitly emphasized building capacity for renewal, learning and transformation in the face of change [57,60,64]. Recent works describe it as multidimensional and process-oriented, as a capacity for self-organization, adaptation, and thriving, often tied to community-level constructs like efficacy and leadership [16,57,65,66]. This trend reflects a move from equilibrium-focused views to dynamic, adaptive perspectives, influenced by climate change that prioritize transformation over recovery.

These different disciplines gave resilience its depth, but they have also introduced its inconsistencies. Alexander [59] argues that resilience has accumulated different meanings, including resistance, recovery, adaptation, and maintaining system integrity, which do not always imply the same outcome [59]. Therefore, resilience should not be understood as a single, universally applicable concept; rather, its meaning reflects the discipline from which a study draws. Accordingly, resilience is increasingly understood as

multidimensional and context-dependent, and its meaning and measurement vary across scales, places, institutions, and systems [18, 60].

3.2.1. Measurement and indicators

Across the 32 reviewed papers on human resilience, 24 provided indicators for measuring it. Social capital and networks emerge as the most repeated indicator, appearing in 17 studies (71%), followed by income (11 papers), education (10 papers), age (9 papers), and gender and health status (each 8 papers). Socioeconomic status, previous experiences, place attachment, and awareness (each 6 papers), form a second tier of recurrent indicators, while less frequent but notable variables include race/ethnicity and adaptive behaviors (3 papers each), as well as leadership, learning, and collective efficacy (2 papers each).

Temporal trends in resilience indicators show that early work (2000–2008) was limited and focused on basic social capital and knowledge as buffers against shock [27]. Between 2009 and 2017, social capital, income, learning, awareness, age, and education gained attention, consistent with recovery-oriented frameworks [60]. From 2018 to 2025, with a notable increase in publications (62% of the total), social networks, socioeconomic status, gender, age, education, and health status dominated. This trend suggests a clear shift towards relational and psycho-social understandings of resilience [57,66] (Fig. 5).

The human resilience indicators can be clustered into four main categories of physiological, psychological, behavioral, and social dimensions as follows.

- Physiological Indicators: physical health, age, gender, mobility.
- Psychological Indicators: place attachment and identity, knowledge, learning from previous experiences, risk perception, skills, self-efficacy, beliefs, mental health, cultural values.
- Behavioral Indicators: coping strategies.
- Social Indicators: social networks, socioeconomic status, income, education, employment, social trust, marital status, minorities.

The reviewed studies indicate a generally consistent direction of association: stronger social capital, higher socioeconomic status, higher knowledge, better health status, higher education, stronger leadership and collective efficacy were generally associated with higher resilience, whereas women and both older and younger age groups were reported as having lower resilience [62,65,67–70]. Several studies found that learning, place-based identity, and past experiences can significantly enhance people's resilience. Song & Li [70] reported that previous disaster experience and learning boosted resilience among Shenzhen residents who had lived through floods by enhancing disaster awareness, self-efficacy, and proactive behaviors [70]. However, place attachment and local identity

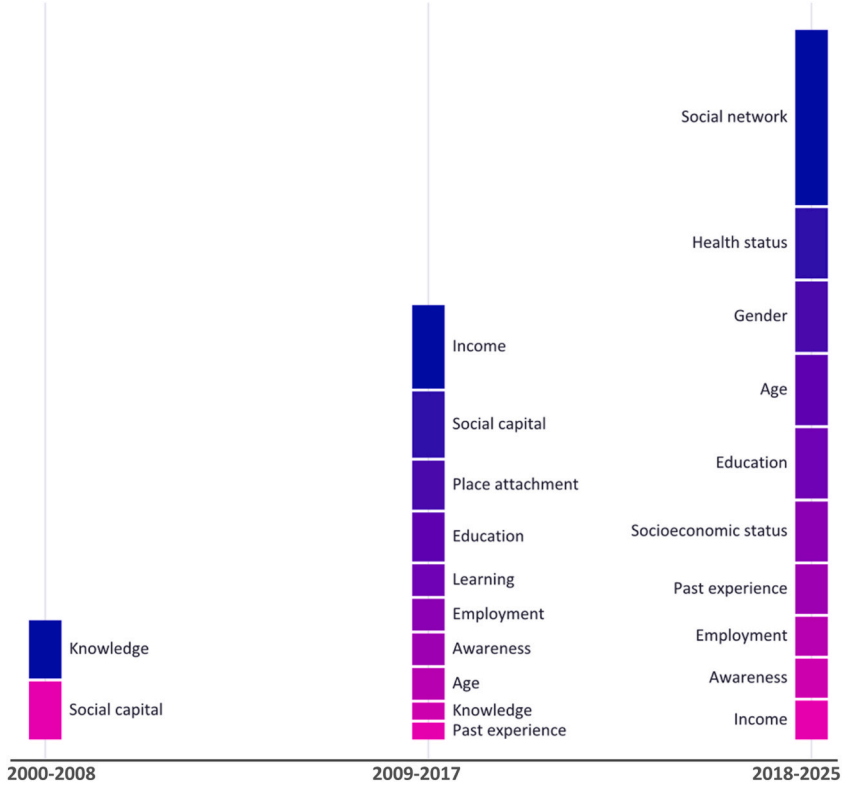


Fig. 5. Thematic evolution of human resilience indicators across time. Each segment represents an indicator, with height showing the share of studies using it, ranked by frequency.

played a dual role: they increased motivation for collective action and long-term adaptation in Ugandan urban slums facing recurrent floods [21] yet could also keep residents in high-risk areas when combined with strong community cohesion rather than mobility options [58].

3.3. Human adaptive capacity

In climate adaptation literature, adaptive capacity is frequently rooted in vulnerability frameworks, as "the ability or potential of a system to respond successfully to climate variability and change and includes adjustments in both behavior and in resources and technologies" [55,71]. It is described as scale- and context-specific, varying across social groups and over time [11,55,72–74].

The broader idea of adaptation traces back to Darwin's work on natural selection, where it described the gradual, genetic-level adjustment of organisms to their environment [17]. The specific phrase "adaptive capacity" first appeared in mid-20th-century organizational theory and sociology to describe how institutions and individuals learn, adjust behavior, and reorganize in the face of change [17]. It entered the climate field only in the late 1990s and early 2000s reframed as "the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses [17]." From that point onward, it became the critical human-centered bridge between vulnerability and resilience frameworks, shifting the focus from genetic or ecological processes to perception, learning, anticipation, deliberate behavioral change [11,17,72,75]. Over time, the understanding of adaptive capacity has evolved from static, resource-based interpretations to more dynamic, process-oriented ones, shaped by awareness, experiences, cultural identity, willingness to act, and coping actions, reflecting a shift toward integrating psychological and behavioral elements [74,76].

A clear distinction arises between short-term coping and long-term capacity. Coping involves immediate, reactive behaviors like basic adjustments [18]. Adaptive capacity, however, involves proactive, transformative elements, such as changing daily routines permanently, which can increase overall potential but requires willingness and resources beyond mere survival [55,76]. The studies repeatedly show that personal exposure to repeated events does not automatically build capacity; instead, learning, identity, and social reinforcement determine whether repeated heatwaves lead to proactive behavior or coping-only strategies [55,76]. For instance, Wolf et al. [22,22] found that strong bonding networks can paradoxically lock people into coping rather than adaptation by reinforcing narratives such as "we've always managed".

Finally, adaptive capacity is consistently nested within resilience frameworks, serving as a tool that enhances a system's ability to withstand and recover from disruptions. While the overarching concept of resilience emphasizes adaptability over stability, adaptive

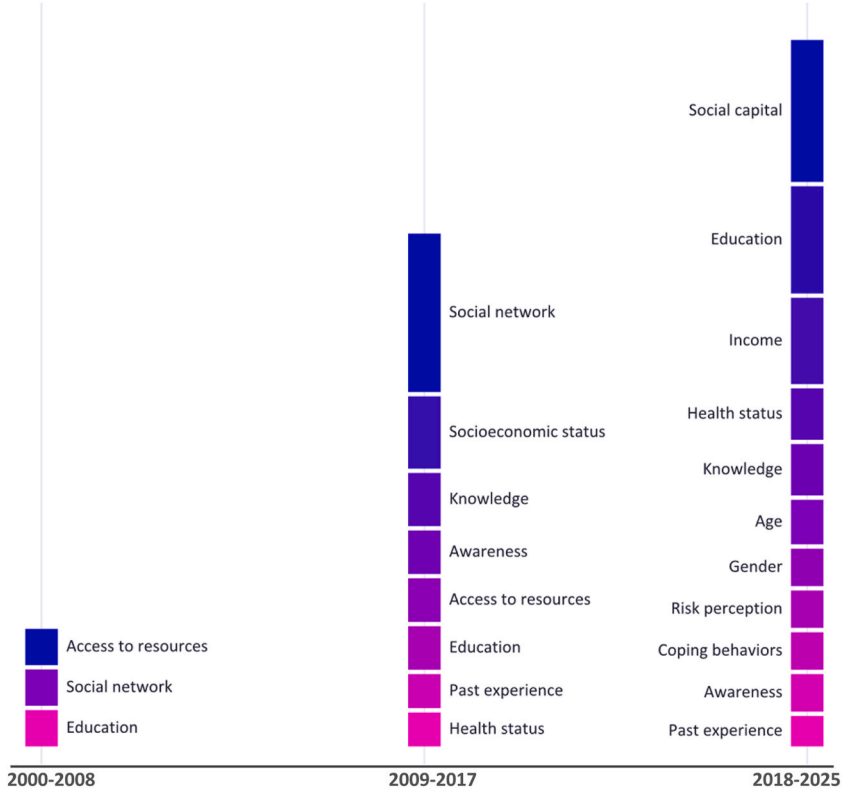


Fig. 6. Thematic evolution of human adaptive capacity indicators across time. Each segment represents an indicator, with height showing the share of studies using it, ranked by frequency.

capacity provides the material, social, and institutional tools that enable learning, innovation, and transformation within the resilience process [26].

3.3.1. Measurement and indicators

Adaptive capacity was often measured within a broader concept. Of the n = 40 studies that operationalized it, n = 20 treated it as a component of a vulnerability, while n = 20 treated it as the primary concept. Across the reviewed papers focused on adaptive capacity, publication output has grown sharply in recent years, with nearly half the studies (n = 19) appearing in 2021–2025 alone. Social capital/network stands out as the single most repeated indicator (n = 39), followed by education (n = 22), income (n = 18), knowledge (n = 14), and health status (n = 12). Socioeconomic status, access to resources, and awareness (each n = 11), age and coping behaviors (each n = 10), previous experience (n = 9), and risk perception (n = 8), and gender (n = 7) form a second tier, while housing tenure (n = 5), attitude (n = 4), self-efficacy (n = 3), and many other variables also recur.

Temporal trends reveal a clear progression. The early period (2000–2008) was characterized by a very limited number of studies, with research focusing primarily on social networks, education, and resource access [11]. The core period (2009–2017) emphasized social network, socioeconomic status, knowledge, awareness, health status, and experience [21,55]. From 2018 onward, social capital, education, income, awareness, risk perception, coping behaviors, and age dominate, pointing to the anticipatory and perceptual dimensions of adaptation [26,76] (Fig. 6).

The findings suggest that people's adaptive capacity is far less predictable than their components. Across the reviewed studies, commonly measured components, such as income, education, and social networks, do not function as stable predictors of adaptation; rather, their effects depend on how they are activated in practice, including through risk perception, trust, prior hazard experience, and local social dynamics. In other words, similar factors can lead to different adaptive outcomes because adaptive capacity is shaped not only by what people have, but also by how context and experience influence what they do. Therefore, the same factors can facilitate or hinder adaptation depending on the situation, timing of assessment, and changing context. For example, in a low-income migrant area of Sydney, people had strong family and community networks, but these stayed unused during heatwaves because residents distrusted institutions and preferred to cope alone [55]. By contrast, in Phoenix, Latino households with similar low incomes adapted better because shared experiences of heat illness and a strong sense of belonging made them more aware of the risk and willing to act early [76]. In Xiamen, residents who had lived longer in the city and faced repeated heat showed growing adaptive capacity through better knowledge and behavior changes, while newer, richer residents who relied only on air-conditioning actually became less proactive [74]. These examples indicate that adaptive capacity is inherently dynamic, evolving through learning loops, repeated hazard exposure, and psychological differences. A research agenda that captures these changing interactions is presented in Section 4.

3.4. Analytical scale

Community-level and individual-level versions of the same concept are not two measures of the same construct. Reid et al. [77] stated that a community-level variable can affect health independently of the same variable measured on individuals [77]. Folke [27] adds that social-ecological systems behave non-linearly, so community resilience is unlikely to be a simple sum of individual resilience, as an additive index assumes [27]. In this review, the concepts differ in how well they move across scales. Wolf et al. [22] note that social capital and health operate at the collective rather than individual level, while Wamsler et al. [78], move from the education of household heads to the adaptive capacity of societies without specifying the steps in between [22,78].

Several of the reviewed studies have assessed this issue directly. Seebauer et al. [56] measured heat vulnerability in Vienna using both mapping and survey approaches and found that the two were almost unrelated ($r < 0.14$) [56]. Watkins et al. [79] compared census block group index scores with household survey responses in Phoenix and found that the association varied depending on the index used and the site examined [79]. Madajewicz [80] developed household outcome measures following Hurricane Sandy that were independent of the usual indicators and found a reversed ranking: middle-income homeowners recovered less easily than poorer renters because resilience as assessed in their study depends partly on owning assets that are themselves at risk [80].

The results also include practical approaches. Wilhelmi and Hayden [48] specify the household-to-neighborhood step rather than assuming it, Song & Li [70] and Bixler et al. [51] use nested models, and Yankson et al. [44] report the full chain from indicator to community score, with the weights justified [44,48,51,70]. These approaches exist, but most studies do not clearly state which one they use.

Overall, the evidence shows that scale is not merely a technical detail but an important part of the concepts and the claims that can be drawn from it. This review therefore suggests that studies state the analytical scale, explain how data are aggregated across levels, and their conclusions scale. In this review, 31 of the 81 studies concluded above the level at which they measured, and 23 of those did not report how individual or household data became a claim about a community.

4. Evidence gaps and research directions for human adaptive capacity

This section synthesizes how adaptive capacity has been conceptualized and operationalized across the reviewed literature, and highlights gaps in existing literature. In this research agenda, adaptive capacity is best understood as the ability of humans to adjust, cope, and respond effectively to actual or anticipated stressors, changes, and disturbances caused by them. It is dynamic, context-specific, and varies based on the type of stressor, time, and characteristics of the system itself. In the human system, physiological, behavioral, psychological and social reactions through moderating sensitivity can facilitate or constrain adaptive capacity.

Positioning adaptive capacity as the unifying thread in this review, it is argued that adaptive capacity does not replace vulnerability

or resilience as concepts. Rather, the three are treated as distinct but interconnected: vulnerability captures susceptibility to harm, resilience captures broader recovery or reorganization of outcomes following disturbance, and adaptive capacity captures the mechanisms that enable adjustment and response. In this sense, adaptive capacity is related to but is analytically distinct from resilience. Some reviewed studies blur this distinction by treating adaptive capacity as a subcomponent of resilience without clear operationalization.

Although this multidimensional perspective is gaining attention, many empirical studies continue to operationalize adaptive capacity through static socioeconomic or community indices [23,26]. These assessments often measure predefined attributes rather than real-world adaptive responses, which limits the understanding of how adaptive capacity is actually mobilized in practice. This practice produces three conceptual and methodological gaps.

(1) Insufficient attention to intra-individual dynamics: the same person can simultaneously show high capacity in one dimension (e.g., strong social networks) and low capacity in another (e.g., physiological ability or low risk perception), yet standard indices simplify these contradictions into a single averaged score [81,82].
(2) Neglect of psychosocial and emotional dimensions: cognitive biases, risk denial, place attachment, optimism, and emotional regulation can shape whether risks are recognized, and behavioral responses are activated, but these factors are rarely measured or questioned [21,22,81].
(3) Limited integration of feedback loops across dimensions: physiological acclimatization, behavioral strategies, psychological reactions, and social norms constantly reinforce or undermine one another (e.g., strong bonding capital reinforcing heat-risk



Fig. 7. Indicators of human adaptive capacity identified in the reviewed literature, grouped into four author-defined domains. Bar length represents the proportion of reviewed papers reporting each indicator.

denial among the seniors, or attitudes impacting willingness to adapt), yet nearly all quantitative models treat these pathways as independent additive components [74,75].

(4) A further measurement gap concerns time: most reviewed assessments are cross-sectional and therefore provide only a snapshot of adaptive capacity. As a result, they cannot capture how adaptive capacity evolves through repeated hazard exposure, learning, and transformation.

(5) Capacity possessed is not distinguished from capacity exercised: reviewed studies assess whether individuals possess resources but often do not examine whether these can actually be exercised when adaptation is required.

These gaps underscore the need for a human-centered approach to move beyond indices-based measurement and map the interplay of body, behavior, mind, and social ties. Fig. 7 shows the indicators of human adaptive capacity identified in the reviewed literature, grouped into the four domains used throughout this section, with bar length representing the proportion of reviewed papers reporting each indicator. The included studies with their indicators are listed in Supplementary Table 1.

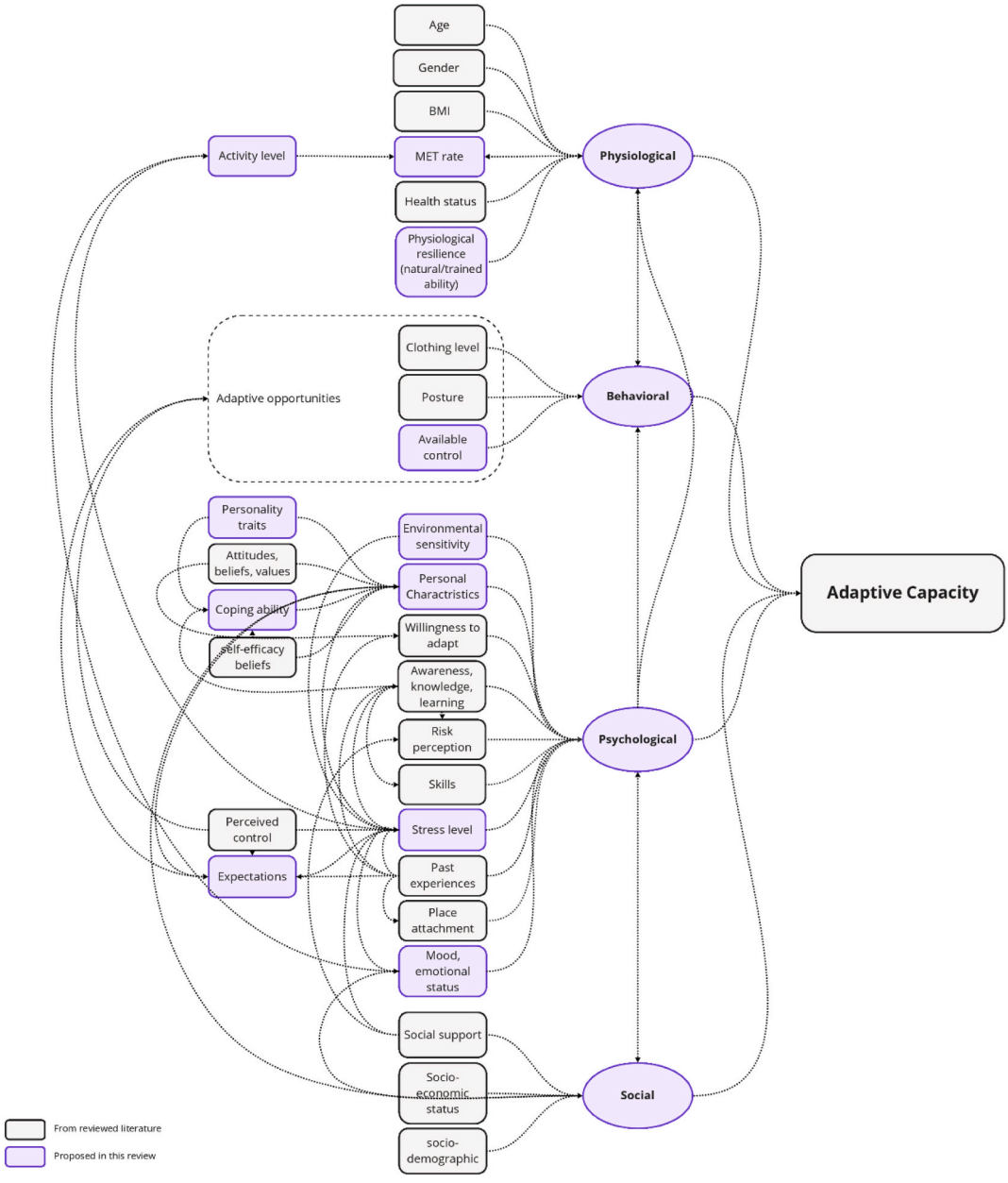


Fig. 8. Research agenda for human adaptive capacity assessment. Grey elements represent components derived from the reviewed literature, while purple elements indicate proposed clusters and indicators introduced in this review.

Section 4.1 categorizes indicators reported across the reviewed studies and identifies variables that no reviewed study measured but would be required to address the gaps above. Extensions drawn from supporting literature are presented as candidate directions for future testing rather than established components of adaptive capacity.

4.1. Dimensions and indicators

The proposed research agenda conceptualizes human adaptive capacity as a multidimensional, interactive process comprising four core aspects: physiological, behavioral, psychological, and social. Fig. 8 illustrates a human-centered research agenda by addressing conceptual silos and emphasizing interconnections. It shows two groups of indicators, literature-derived indicators identified in the reviewed papers, and author-proposed elements as additions introduced in this paper. Author-proposed indicators are concentrated in the physiological, behavioral and psychological aspects, which is where gaps 1, 2, 4, and 5 fall.

Physiological dimension refers to the body's inherent or trained capacity to withstand environmental stressors. Indicators identified in the reviewed adaptive-capacity studies include age [55,72,83], gender [21,72,74], Body Mass Index (BMI) [74,84], and health status [58,85] with heat-related studies also emphasizing older age and pre-existing health conditions in adaptive-capacity contexts [74,86]. Age, health status, and BMI are usually treated as sensitivity variables in disaster-vulnerability literature [87]. They appear here under adaptive capacity because this reflects how the reviewed studies classify them. This overlap reflects the finding that vulnerable groups often have both higher sensitivity and lower adaptive capacity, meaning that the same attributes can inform both dimensions [72]. There is also a basis for placing physiological attributes under adaptive capacity, based on the distinction between fixed susceptibility and the ability to adapt. Acclimatization is dynamic and reversible, unlike sensitivity, which reflects a more fixed response to heat. Age and chronic illness can limit the body's ability to adjust, so they can be considered as indicators of adaptive capacity rather than only susceptibility. This observation aligns with the IPCC [2], which defined adaptive capacity as the ability to adjust to potential impact.

Two author-proposed indicators are added to this domain. Metabolic rate (influenced by activity level) and physiological resilience address gaps 1 and 4: the literature operationalizes the body through fixed attributes such as age, BMI, and health status, and no reviewed study measured the body's capacity to withstand or recover from a stressor. They are stated here as testable propositions, that people with the same age, BMI, and health status differ in adaptive capacity in ways those attributes do not capture. Both are consistent with thermal adaptation research, which identifies physiological adaptation as a core adaptive process, including heat-acclimatory changes (e.g., reduced metabolic rate) that increase heat tolerance and reduce imposed stress. Moreover, physiological resilience and activity-related metabolic adjustment can shape thermal strain, coping, and recovery, supporting their inclusion in the adaptive capacity research [3,88,89].

Behavioral dimension comprises adaptive opportunities individuals take to cope with or mitigate hazards. Reviewed studies explicitly describe behavioral adjustment as part of adaptive capacity, including short-term coping and longer-term behavioral responses [11,17,58]. Empirical examples include behavioral changes, livelihood adjustments, and relocation choices [58], as well as cooling tactics and seeking cooler places during heat events [90].

Available control is a review-proposed addition addressing gap 5. Reviewed studies assess whether people hold resources but not whether they can act on them (i.e., capacity that is possessed and capacity that is exercised are not distinguished). Available control (i.e., the presence of options a person can operate in practice through operable features or passive strategies) is proposed as a variable because adaptive actions occur only when individuals both perceive an option as available and are able to use it [91,92].

Psychological dimension involves cognitive and emotional processes that shape adaptation. Indicators identified in the reviewed adaptive-capacity studies include awareness [81], risk perception [75,78], willingness to adapt [75,76], past experiences [51,55], attitudes and beliefs [55,73], self-efficacy [21,72], place attachment [21,76] and perceived control [21]. In particular, adaptive capacity is described as a socio-psychological process shaped by cognitive, and affective mechanisms [81].

Four author-proposed indicators extend this domain. Mood and emotional status address gap 2: although the literature covers cognitive aspect through awareness and risk perception, affective dimensions are almost entirely absent. Mood is therefore proposed as a short-timescale state that may affect behavioral responses. Personal characteristics, including personality trait and coping ability, address the same gap. While literature measures situation-specific appraisals, it does not capture stable individual differences that may explain why people facing the same hazard perceive it differently. Traits such as openness, conscientiousness, and emotional stability have been associated with higher adaptive capacity scores and neuroticism with lower scores [93,94]. Environmental sensitivity is proposed on a similar basis, supported by evidence that individuals differ systematically in how they perceive and process environmental stimuli including differences in sensory sensitivity and emotional and physiological reactivity [95,96]. Expectations address gap 4: none of the reviewed studies examined whether repeated exposure alters an individual's response to the same stressor. It can be linked to habituation in psychophysics, where repeated exposure to a stimulus gradually reduces the strength of the response it produces [3,97], and therefore changes adaptive capacity over time. Lastly, stress level addresses gap 1 because it varies within individuals over time. Moderate stress may build resilience, but chronic stress can overwhelm adaptive capacity [98,99].

Although age is a physiological indicator, it also affects several of these psychological indicators and can influence adaptive capacity in different ways. Risk perception varies with age, education and prior experience [50]. Previous hazard experience can strengthen adaptive capacity [74,78], while cognitive aging and reliance on past experience may reduce it. Age therefore affects adaptive capacity through two pathways: physiological potential and acclimatization, and cognitive and experiential processes.

Social dimension focuses on social support, and socioeconomic factors that enable collective adaptation. Literature-derived indicators in the reviewed adaptive-capacity studies include social support/social capital/networks, socioeconomic factors such as income, education, and employment, and socio-demographic elements including race/ethnicity and minority status [21,26,83,85,100].

In these studies, marginalized or minority population groups are often treated more as markers of unequal social conditions, including differential access to resources, information, and adaptive opportunities. These studies also highlight the importance of access to resources, information, and networks in shaping uneven adaptive capacity across groups and places [83]. This aspect contains no author-proposed additions, since the reviewed literature covers it most consistently.

5. Conclusions

This scoping review synthesizes studies on human vulnerability, resilience, and adaptive capacity in built environments, highlighting their evolution, interconnections, metrics, and implications for addressing climate-related hazards. It further shows how adaptive capacity serves as a unifying thread, enabling practical pathways to reduce vulnerability and enhance resilience against changing environmental conditions. Key insights from this review underscore a notable evolution in conceptual frameworks over time (RQ1). Early studies predominantly used static, hazard-focused approaches to vulnerability, emphasizing exposure and sensitivity as fixed attributes via indices like SoVI based on demographics (age, income, race) tied to socioeconomic inequalities and geographic risks [37]. In contrast, more recent work shifts towards dynamic, human-centered integrations, incorporating psycho-social elements like social capital, risk perception, and learning [16,81]. Resilience emerges as a process-oriented concept, stressing recovery and transformation [27,65], while adaptive capacity acts as a bridge, enabling proactive adjustments through resources like education, networks, and institutional support [17,55]. Rather than opposite ends of a single scale, in principle, the three describe different aspects of one dynamic: vulnerability the susceptibility to harm, resilience the capacity to recover, and adaptive capacity the ability to adjust (RQ3).

Findings show that vulnerability, resilience, and adaptive capacity are operationalized using largely overlapping sets of indicators, suggesting that these concepts are not empirically distinguishable as currently measured (RQ2, RQ3). Shared assessment indicators further clarify these links. Socioeconomic factors like income and education are common across concepts, reducing vulnerability while enhancing resilience and adaptive capacity. Psychological indicators, such as prior experiences, risk perception and knowledge, bridge them, fostering adaptive behaviors. Moreover, physiological indicators like age, gender, and health conditions appear across all three concepts. Through indicator clustering, clear categories emerge, including physiological, psychological, behavioral and social dimensions consistent across the three concepts. This overlap of indicators reinforces the pattern described above: behavioral indicators are present in vulnerability itself, not only in resilience and adaptive capacity. This is consistent with the recent shift toward more dynamic, human-centered vulnerability assessments and shows that adaptive capacity is frequently nested within vulnerability in the reviewed studies. In other cases, the same indicators are used in opposite ways, increasing resilience while reducing vulnerability. Neither pattern gives the concepts their own indicators: 33 of the 58 indicator groups are used for all three concepts and concept-exclusive indicators account for less than 5% of all indicator sets. What differs is emphasis, with vulnerability focused more on demographic factors and adaptive capacity towards knowledge, social capital and other capacities (RQ3). This extensive indicator overlap reflects conceptual interdependence of the three concepts, that the reviewed literature has not yet translated into empirically distinguishable measurement categories.

However, current gaps exist in measurement and conceptualization (RQ4). Measurement gaps include a lack of standardized human indicators, with many studies relying on subjective indices that overlook dynamic interactions, which is challenging to gauge. Limited longitudinal models fail to capture how all three concepts evolve over time, such as through repeated hazard exposure. Conceptual gaps involve ambiguous boundaries between resilience and adaptive capacity, where the latter is often treated as a subcomponent without distinct operationalization, and assessments also tend to rely on predefined attributes instead of real-world responses, limiting understanding of how systems actually mobilize and what factors influence them. Furthermore, unexplored areas include behavioral and psychological dimensions, like cognitive biases or emotional responses, which influence adaptation but are rarely quantified. Limitations of the reviewed literature, such as cross-sectional designs that restrict causal inference and context-specific findings that limit generalizability, underscore the need for more interdisciplinary, scalable approaches.

The review has its own limitations. Screening was assisted by active learning, so only part of the retrieved records was manually reviewed. However, the stopping criteria indicate that most eligible studies were captured, but some may remain among the records not reviewed. Backward snowballing also identified eligible studies absent from the search results, indicating that the search string and the three datasets did not cover the whole of the relevant literature. We also chose a broad scope across hazards and disciplines rather than focusing on one specific hazard or field. This allowed us to compare vulnerability, resilience, and adaptive capacity across the wider human-dimensions literature, but it also limited the depth of hazard- or discipline-specific analysis within the review. These trade-offs are inherent to any review at this scale, and the machine-learning assisted approach made it feasible to search broadly across disciplines rather than narrowing the scope.

The proposed human-centered research agenda translates the review findings into a set of testable propositions for future research and assessment (RQ4). Rather than treating adaptation as a fixed trait derived from indicators, the research agenda emphasizes how capacity is activated, constrained, and reshaped through interactions among physiological condition, behavior, cognition, and social context across different stages of disturbance. This shift is important because it enables future studies to examine mechanisms, not only profiles (who appear more or less prepared). It also offers a shared conceptual basis for future studies, while retaining flexibility for context- and hazard-specific operationalization. The agenda is not a validated model: its author-proposed indicators, which derive from literature outside this review's inclusion criteria and remain propositions for empirical testing rather than established components of adaptive capacity.

In conclusion, this review highlights adaptive capacity as the pivotal bridge between vulnerability and resilience, essential for withstanding climate-induced stressors through empirical, context-specific assessments. Moving the field forward requires more than

adding new indicators; it requires a clearer understanding of human adaptation, specifically, how body, mind, behavior, and society interact, and how change can be captured through time and repeated disruption. Future research directions should prioritize longitudinal, mixed-methods studies in underrepresented areas and integrate behavioral and psychological sciences for indicators. To better address temporal dynamics, studies should adopt phase-based and repeated-measure designs that follow the same populations across hazard events, combining resource-based indicators with observed adaptive responses to capture learning, feedback, and changing constraints over time. Future research should therefore focus on mechanisms and processes, using designs that allow comparison across cases while also accounting for local context and real-life constraints on response. Bridging these gaps will foster more holistic strategies to support human thriving against environmental challenges.

CRediT authorship contribution statement

Mina Moayyedi: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Rania Christoforou:** Writing – review & editing, Supervision, Methodology. **Marcel Schweiker:** Writing – review & editing, Supervision, Methodology, Funding acquisition.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data supporting the findings of this study are included within the article and its supplementary material.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2026.106533.

Data availability

Data will be made available on request.

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