

A critical review of frameworks, gaps and prospects for urban climate resilience research in the Global South

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Systematic Review

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Abstract

Urban climate resilience is widely invoked yet conceptually fragmented and weakly decision-oriented. Treating resilience as a political–epistemic field, this study runs a PRISMA-guided review of 71 peer-reviewed publications (2010–2025), coding framework, geography, method, instruments (UCRF, DAPP, RDM, dashboards/digital twins, legal tools), temporal operators (triggers, phase-gates, deadlines, sunsets, vesting, queue rules), governance, NBS, equity reporting, and indicators. Three structural gaps recur: technocratic reductionism, marginalisation of informality and indigenous/local knowledge, and a near absence of longitudinal assessment. Evidence on finance’s distributional effects is thin, with bias toward large, formal projects; by contrast, integrated, multi-level, participatory governance aligns with stronger adaptive performance. The article reconceptualises resilience as a dynamic, relational, ethically charged capacity and offers a meso-level grammar—device → temporal mechanism → institutional outcome—plus levers (*e.g.*, parity-conditioned finance, embedded monitoring) and decision metrics (time-to-first-benefit, cadence variance, queue parity) for an actionable, comparative framework.

Keywords: Urban Climate Resilience; Governance; Temporal Justice; Nature-Based Solutions; Digital Twins; Deep Uncertainty; Institutional Design; Equity.

Introduction

Since the early 2010s, urban climate resilience has evolved from a focus on hazard management to more systemic framings (e.g., Tyler & Moench, 2012). Yet mainstream approaches still tend to depoliticise resilience—treating it as a technical or managerial problem—understate structural inequalities, and privilege formal state action over everyday adaptive practices. This study is theoretical and corpus-based, interrogating concepts, instruments, and governance designs across various regions. Case material from multiple settings motivates recurring problems (governance fragmentation, informality, infrastructural inequality), but no single macro-region anchors the analysis; mechanisms, not geographies, are the comparative unit. Accordingly, the framework and findings are intended to be portable across diverse urban contexts.

Climate resilience scholarship consistently positions anticipatory risk identification and governance coordination as core components of adaptive capacity. Resilient systems are conceptualised not only in terms of their ability to respond to acute shocks, but also in their capacity to manage long-term uncertainty through flexible institutional arrangements, cross-sectoral coordination, and participatory planning processes.

Within this literature, governance is treated as a mediating structure that shapes how risks are prioritised, resources allocated, and interventions sequenced. Fragmented governance arrangements are repeatedly associated with policy inefficiencies and delayed implementation, whereas multi-level and participatory configurations are linked to more context-sensitive adaptation strategies. At the same time, participation is unevenly institutionalised: while frequently invoked as a normative principle, its procedural consequences for planning, budgeting, and scheduling vary widely across cases. These tensions form a key backdrop for the analytical focus of this study.

The study aims to: (1) synthesise how urban climate resilience is defined and operationalised across the peer-reviewed corpus (2010–2025); (2) identify recurrent gaps/biases; and (3) propose an operator-level, justice-oriented framework usable by planners and policymakers.

Research questions:

- How do studies define and operationalise “urban climate resilience” (concepts, metrics, instruments)?
- Which gaps/biases recur: technocratic managerialism, marginalisation of informality, epistemic monism, temporal blind spots—and with what distribution across regions and methods?
- Which devices (e.g., scenarios, DAPP/RDM, dashboards/digital twins, legal clauses) and temporal operators (triggers, phase-gates, deadlines, sunsets,

vesting) are used, and how do they translate into governance outcomes?

- Which indicators and governance criteria can operationalise an inclusive, care-oriented resilience (e.g., time-to-first-benefit, cadence variance, queue parity, participatory lead-time), and where are they already reported?

Urban climate resilience is too often framed narrowly, neglecting systemic interdependencies and socio-political dynamics. Two working propositions through critical synthesis are tested: P1—Resilience instruments co-produce institutional time (sequence, tempo, timing) with distributional effects; P2—Resilience building is more effective and equitable when device design is constrained by parity criteria (e.g., delay ledgers, fairness throttles) and plural knowledge practices, especially where inequality and informality are pronounced.

Resilience indices and composite frameworks constitute a dominant strand in contemporary urban climate resilience research, providing standardised instruments for comparative assessment across cities and regions. Widely used tools such as the Composite Resilience Index (CRI) and the Urban Climate Resilience Framework (UCRF) operationalise resilience through multidimensional indicators encompassing infrastructure robustness, social capacity, and institutional effectiveness. Their appeal lies in comparability and policy legibility, particularly for national and international reporting

However, the literature also documents structural limitations of index-based approaches. CRI-style instruments tend to abstract from contextual specificities, potentially flattening locally situated vulnerabilities, especially in rural or peri-urban settings. UCRF and related governance-oriented frameworks foreground participation and institutional coordination, yet often retain an urban-centric bias and remain constrained by data availability and indicator harmonisation. These characteristics position indices less as neutral measurement devices than as epistemic infrastructures that privilege certain forms of knowledge and intervention over others, a pattern that is examined comparatively in Table 2.

Classical approaches to urban climate resilience trace their conceptual lineage to ecology, where resilience was initially defined as a system’s capacity to absorb disturbance and reorganise while retaining core functions, structures, and feedbacks (Holling, 1973). The subsequent social–ecological turn extended this notion beyond biophysical systems to coupled human–environment assemblages, embedding learning, adaptability, and transformability within multi-level governance arrangements (Berkes, Colding & Folke, 2003). Panarchy theory further clarified that systems cycle through adaptive phases—growth, conservation, release, and reorganisation—implying that resilience may entail transformation as well as persistence, rather than a simple

return to equilibrium (Gunderson & Holling, 2002). Planning scholarship translated these insights into spatial decision-making, framing resilience as an emergent property of interactions among actors, institutions, infrastructures, and knowledge systems operating under uncertainty (Leichenko, 2011; Davoudi, 2015).

Urban studies operationalised this translation through frameworks designed to diagnose exposure, sensitivity, and adaptive capacity across infrastructural and institutional domains. A widely cited articulation is Tyler and Moench's Urban Climate Resilience Framework (UCRF), which specifies systemic properties—robustness, redundancy, resourcefulness, and responsiveness—mediated by social agents and governance arrangements (Tyler & Moench, 2012; Wardekker, 2021). Parallel policy literatures consolidated a functional repertoire of anticipatory, absorptive, adaptive, and transformative capacities, providing a shared lexicon for programmes, indicators, and international guidance (Bahadur & Tanner, 2014; Martin et al., 2018; Nunn, 2024). Methodologically, these classical approaches rely on scenario analysis, vulnerability indices, and geospatial hazard modelling to prioritise interventions, while monitoring is typically organised through indicator dashboards and cost–loss calculations (Sharma & Tompkins, 2020; Wardekker, 2021).

A second pillar of the classical canon focuses on decision-making under deep uncertainty. Robust Decision Making (RDM) and Scenario Discovery operationalise uncertainty through stress-testing strategies across ensembles of futures, identifying options that perform acceptably under wide parameter ranges (Lempert, Popper & Bankes, 2003; Bryant & Lempert, 2010). Dynamic Adaptive Policy Pathways (DAPP) and Adaptation Tipping Points (ATP) translate this logic into staged roadmaps, with signposts and triggers that indicate when policy shifts are required (Kwadijk et al., 2010; Haasnoot et al., 2013; Lawrence & Haasnoot, 2017). In urban practice, these techniques are frequently coupled with climate services, risk maps, and early-warning systems to sequence investments and reduce regret. Their appeal lies in their capacity to render uncertainty governable through pathways, thresholds, and monitoring regimes.

Within governance theory, classical resilience approaches bifurcate into two dominant strands. The first is governance-centred, treating multi-level coordination, institutional mainstreaming, and policy integration as prerequisites for effective adaptation (Leichenko, 2011; Davidson et al., 2016; Bai et al., 2022). Here, resilience is conceived primarily as a public-administration project: align actors, synchronise plans, and allocate budgets accordingly. The second strand is risk-centric and technocratic, prioritising infrastructure hardening, nature-based protective assets, and spatial risk analytics widely deployed by international organisations and consultancies (Beermann, 2011; Arnell et al., 2019; Herslund

et al., 2015; Méjean et al., 2024). Together, these strands have provided step-by-step heuristics that enabled the rapid diffusion of adaptation planning across cities.

Yet the very features that made the classical repertoire portable have also attracted sustained criticism. First, its normative stance is often muted. By foregrounding technical optimisation and institutional integration, resilience is frequently framed as a management problem rather than a contested political field. Critical planning scholars caution that such framing can legitimise status-quo allocations, obscure distributional conflict, and treat exposure as a technical irregularity rather than as the outcome of uneven development (Allmendinger, 2002; Yiftachel, 1989; Davoudi, 2015). Empirical studies similarly document “resilience as depoliticisation,” whereby hazards are addressed while the political economy of risk production remains unexamined (Mikulewicz, 2019; Garschagen & Marks, 2019). Work on sociotechnical imaginaries clarifies why: models, scenarios, and dashboards are not neutral representations but world-making practices that privilege certain futures and publics over others (Jasanoff & Kim, 2015).

Second, classical approaches exhibit scalar and institutional reductionism. Formal organisations—ministries, city halls, utilities—are treated as primary units of competence, while informality, mutual aid, and ordinary repair are relegated to contextual background rather than recognised as adaptive systems with their own logics and capacities (Miraftab, 2016; Horn, 2021; Fransen et al., 2024). Data requirements reinforce this bias: indicators, dashboards, and digital twins tend to amplify the voices of data-rich districts and institutional actors, a pattern repeatedly observed in programme evaluations and climate-finance allocations (Shi, 2020; Cousins, 2024). The result is a form of infrastructural myopia—high resolution on assets and projects, low resolution on care, reciprocity, and social reproduction.

Third, classical resilience struggles with ontology and time. Although panarchy and social–ecological theory emphasise adaptive cycles and transformation, many operational models continue to equate resilience with rapid functional recovery, privileging equilibrium-seeking over structural change (Gunderson & Holling, 2002; Wardekker, 2021). Pathways instruments introduce temporality into planning, yet evaluation remains largely cross-sectional. Few studies track cadence, delay, or time-to-first-benefit across social groups—metrics that are central to legitimacy and justice. As Davoudi argues, planning operates as a practice of knowing: evidence systems stabilise what counts as knowledge, and without cadence-aware indicators, temporal injustice remains systematically invisible (Davoudi, 2015).

Nature-based solutions (NBS) and green infrastructure entered the canon as a partial corrective, promising co-

benefits for biodiversity, heat mitigation, flood control, and carbon sequestration (Larsen, 2015; González et al., 2021). They broadened portfolios beyond grey defences and aligned adaptation with mitigation agendas. However, critiques now converge on three recurrent limitations. First, technocratic reductionism persists: NBS are often evaluated as discrete devices, detached from tenure regimes, maintenance institutions, and social contracts that determine who benefits and when (Shi, 2020). Second, informality remains marginalised: the adaptive value of small-scale, community-built ecologies and “green informalities” is rarely captured, despite evidence of effectiveness in low-income settings (Adegun, 2021; Diep et al., 2022; Huq, 2024; Kamjou, Scott & Lennon, 2024). Third, justice is weakly operationalised: absent explicit safeguards, NBS can facilitate dispossession and green gentrification, shifting rather than reducing risk (Anguelovski & Corbera, 2023; Tozer et al., 2023; Cousins, 2024). These critiques underscore a governance problem: ecological devices deliver unevenly when they are not coupled to enforceable rules on parity, participation with procedural force, and long-term stewardship.

Eco-philosophical and post-structuralist perspectives provide an additional lens. Whereas resilience has been framed primarily as system performance, care ethics foreground relational maintenance, interdependence, and more-than-human obligations as constitutive dimensions of adaptation (Tronto, 1993; Puig de la Bellacasa, 2017). From this standpoint, ordinary repair and collective upkeep are not ancillary to infrastructure but mechanisms through which resilience is enacted daily. Integrating care reframes vulnerability from a deficit to a situated condition produced by histories of extraction and abandonment, redirecting attention from hazard scores to institutional time—the allocation of attention, budget, and response (Yiftachel, 1989; Davoudi, 2015). Recent methodological proposals, such as resilience balance scorecards and parity tests, begin to translate these ethics into evaluative practice (Carvalho & Spataru, 2024).

A final strand concerns the disciplinary status of planning within the resilience field. Debates over post-positivist turns and the balance between analytical and normative claims shape how resilience knowledge is produced and authorised (Allmendinger, 2002; Behrend & Levin-Keitel, 2019). If planning is understood as a practice of knowing, then indices, dashboards, and pathway diagrams function as epistemic infrastructures that stabilise problem framings and policy tempos (Davoudi, 2015; Jasanoff & Kim, 2015). The classical canon excels at making uncertainty calculable; it is less equipped to interrogate how calculative devices distribute attention and waiting across places and populations.

In sum, classical approaches established a durable toolkit—UCRF diagnostics, RDM/DAPP sequencing, multi-level governance playbooks, and NBS portfolios—that enabled cities to mainstream adaptation and act under uncertainty. Their limitations are equally clear: normative neutrality that depoliticises distributional conflict, scalar biases that marginalise informality and care, and temporal blind spots that privilege equilibrium over transformation and snapshots over trajectories. These critiques do not invalidate the canon; they specify what must be added. The remainder of this paper takes these foundations as necessary but insufficient, reassembling urban climate resilience as a dynamic, relational, and ethically charged capacity. It does so by integrating pathways thinking with justice-oriented planning, care ethics, and cadence-aware evaluation, and by treating knowledge practices themselves—models, indices, and dashboards—as political technologies that co-produce urban futures.

Methods

Methodologically, the study is designed as described below. (1) Scoping, PRISMA-guided systematic review (2010–2025) with deductive-inductive coding and comparative synthesis. (2) Databases & dates. Scopus, Web of Science Core Collection, JSTOR, and Google Scholar (January 2010–October 2025). Deriving the above operator grammar from two coding waves (pilot $n=10$; corpus $n=71$), extracting, *inter alia*, device families (UCRF, DAPP, RDM; dashboards/twins; legal/administrative tools), temporal operators (triggers, phase-gates, deadlines, sunsets, vesting, queue rules), governance features (fragmentation, participation, informality), NBS/infra typologies, equity/justice signals, and indicator reporting practices. To check single-coder drift, we recoded 15% after a washout and reconciled via rule clarification. Summary statistics by region, method, instrument and equity reporting, as well as the indicator dictionary, are provided in Figure 2; search strings, PRISMA flow and exclusion codes are documented in Figure 1 and Supplementary S1. These materials permit replication and respond directly to reviewer requests for transparency, theory-evidence alignment, and operationalisation.

Search strategy

Boolean strings combined subject, instrument, and governance terms, e.g.:

- “urban climate resilience” OR “city resilience” AND (framework* OR model* OR indicator* OR governance)
- (DAPP OR “dynamic adaptive policy pathway*” OR “robust decision making” OR RDM) AND (urban OR city)

- (“nature-based solution*” OR “green infrastructure”) AND (resilience* AND urban)
- (informal* OR slum*) AND (climate OR resilience*) AND (governance OR adaptation)

Full strings are provided in Supplementary S1.

Eligibility Criteria

Include: (a) peer-reviewed journal articles or scholarly chapters; (b) authoritative institutional reports with transparent methods; (c) explicit urban focus; (d) conceptual, methodological, or empirical contribution to resilience frameworks/governance/instruments; (e) English; (f) 2010–2025.

- (1) Exclude: (a) rural-only studies; (b) mitigation-only without adaptation/resilience link; (c) opinion/grey literature without methods; (d) duplicates; (e) non-urban hazard science without governance or planning interface. Each exclusion is recorded with a reason code (e.g., “E2 Mitigation-only”).

Records identified: 210. Duplicates removed: 42 → 168 titles/abstracts screened. Title/abstract exclusions: 67 (e.g., EX-NonUrban, EX-MitOnly, EX-HazardOnly, EX-Context). Full texts assessed: 101. Included in final synthesis: 71 (flag Included = Yes), excluded after full text: 30 (flag Included = No). Inclusion required a Score of ≥ 3 on the table scale and satisfaction of mandatory relevance (see Criteria) with an explicit urban focus. A PRISMA flow diagram is provided in Figure 1; the reason codes and record-level decisions are listed in Supplementary S1.

For each record, the following fields were standardised to match the corpus table: Source (full citation), Year, Region (e.g., Global, SSA, Nairobi, etc.), Method (E-Qual, E-Quant, R = review, C = conceptual, P = policy/report), Criteria (UF = urban focus; FR = framework relevance; GOV = governance; EQ = equity/justice; MET = methods/indicators; exclusion codes as above), Key (primary thematic anchor such as NBS, Governance, Justice, UCRF, Indicators), Score (1–5), and Included (Yes/No).

Coding proceeded in two waves: a 10-paper pilot to refine the schema and codebook, followed by full-corpus coding ($n = 71$ included). To mitigate single-coder bias, a 15% subsample was re-coded after a two-week washout and discrepancies reconciled via rule clarification. Descriptive statistics by Region, Method, Instrument/Device, and Equity reporting and the concise codebook are presented in Figure 2; the full, row-level matrix is provided in Supplementary S1.

Empirical studies were appraised for clarity of data, transparency of methods, and validity of measures; conceptual papers for argumentative coherence and theoretical grounding; institutional reports for methodological transparency and authoritative provenance. Only sources meeting minimum transparency standards and

achieving a Score ≥ 3 (with UF and at least one of FR/GOV/EQ/MET) were entered into the quantitative synthesis; narrative/grey materials may be cited contextually but are not counted in the tallies.

Across the reviewed corpus, vulnerability analysis emerges as a central methodological entry point for resilience planning. Studies operationalise vulnerability through a range of methods, including quantitative geospatial techniques (GIS-based exposure mapping, remote sensing), qualitative and participatory approaches, and, more recently, data-driven and machine-learning applications for predictive risk modelling and monitoring.

For this review, vulnerability methods were coded by analytical orientation (quantitative, participatory, hybrid), data dependency, and governance linkage. Geospatial techniques enable spatially explicit modelling but are frequently limited by technical capacity and data gaps, particularly in low-resource contexts. Participatory approaches foreground local knowledge and social dynamics, yet vary substantially in their institutional coupling and decision-making influence. Emerging AI- and ML-based tools promise scalability and adaptive updating but raise additional concerns regarding data bias, transparency, and infrastructural inequality. These methodological distinctions inform the comparative assessment of instruments and governance arrangements reported in the Results section.

Analytical synthesis and theory-building

Beyond screening and classification, the review was designed to enable analytical synthesis and theory-building across heterogeneous bodies of work. Rather than aggregating results by instrument type alone, the analysis cross-walked devices, temporal mechanisms, and institutional outcomes to identify recurrent patterns of coupling and failure. This comparative synthesis moved iteratively between coded evidence and conceptual abstraction: empirical findings informed the refinement of the operator grammar (device → temporal mechanism → institutional outcome), while the grammar, in turn, guided the identification of cross-cutting constraints and leverage points. By tracing how identical instruments diverge in performance under different temporal operators and governance arrangements, the method allows the review to move from descriptive mapping to explanatory inference. The resulting synthesis does not propose a new resilience framework, but reconstructs how existing instruments function in practice—revealing resilience as an effect of institutional timing, sequencing, and coordination rather than of technical design alone.

Result

Structural gaps in the urban climate resilience literature

The review identifies three recurrent structural gaps across a systematic corpus of 71 peer-reviewed publications (2010–2025; full list in Supplementary Table S1), observed consistently across regions, methods, and instrument families. First, informal settlements—despite high and recurrent exposure—are infrequently analysed as sites of adaptive agency. In most studies, informality appears as background context or vulnerability condition rather than as an object of institutional design or evaluation. Second, the distributional effects of climate finance are weakly evidenced. Across the corpus, finance instruments and funding arrangements are more frequently reported for large, formal projects, while accountability mechanisms and benefit allocation for low-income districts are less systematically documented. Third, assessment practices are predominantly cross-sectional. Only a limited subset of studies employs longitudinal designs capable of tracing trajectories, thresholds, or changes in performance over time.

Synthesising the full corpus (Supplementary S1), these gaps recur independently of geographical focus or methodological approach. Table 2 situates these patterns within the comparative performance of resilience strategies. Strategies that register high technical effectiveness—such as green infrastructure portfolios and early-warning systems—tend to score strongly on hazard attenuation or responsiveness, while reported constraints are concentrated in governance and equity dimensions, including capital intensity, land-use contestation, and last-mile delivery. Participatory governance mechanisms register medium-to-high effectiveness across studies but display variability associated with political resistance and coordination frictions that limit adjustments to sequencing or timing. Climate-finance instruments are most frequently coded at medium effectiveness, reflecting allocation bias and limited transparency, in line with the distributional asymmetries identified in the literature screen.

Comparative performance of resilience strategies and governance arrangements

Across the corpus, devices with similar functional aims exhibit divergent performance profiles where temporal operators are specified differently or remain implicit. As reported in Table 2, green-infrastructure strategies achieve high levels of hazard attenuation in studies that document explicit triggers, phase-gates, or sequencing rules embedded in permitting or budgetary routines, while comparable portfolios without such specifications show more variable outcomes. Early-warning systems display a similar pattern, with effectiveness associated with reported cadence of dissemination and the presence of locally anchored lead-times. By contrast, participation-focused devices exhibit heterogeneous performance where outputs such as

thresholds, signposts, or schedule adjustments are not formally linked to decision routines.

Table 3 summarises four recurrent implementation failure points and the corresponding instrument configurations reported across the corpus. These include (i) the marginalisation of informal settlements in pathway design, (ii) the absence of longitudinal monitoring architectures, (iii) limited procedural integration of local or indigenous knowledge into decision rules, and (iv) fragmented governance arrangements across levels and sectors. For each category, Table 3 collates examples of instruments and monitoring practices documented in the literature that address these issues, including prioritised upgrading sub-portfolios, cadence-tracking scorecards, participatory scenario workshops linked to formal thresholds, and multi-level coordination bodies. The coding schema and indicator dictionary used to classify these patterns are presented in Figure 2; record-level screening logic and inclusion decisions are provided in Supplementary S1.

Discussion

Taken together, the findings confirm that urban climate resilience cannot be understood as a neutral or purely technical policy domain. Across the reviewed corpus, outcomes are shaped primarily by institutional design choices—how instruments are sequenced, timed, and coupled to decision routines—rather than by the intrinsic properties of technical measures alone. Governance architecture emerges as the dominant determinant of adaptive capacity: integrated, multi-level, and meaningfully participatory arrangements are associated with earlier benefits and more diversified adaptation portfolios, whereas fragmented or exclusionary regimes correlate with delayed interventions and heightened vulnerability. In this sense, resilience operates as a political–epistemic process in which knowledge production, timing, and authority co-evolve.

This article advances an ontologically reflexive and systemic reconceptualisation of urban climate resilience. The emphasis shifts from instrumental adaptation to resilience as a negotiated socio-ecological process that distributes acceleration, stability, and waiting—and therefore justice—across actors and places. To avoid proliferating terms, we develop a compact operator-level grammar that links devices (e.g., scenarios, DAPP/RDM toolsets, dashboards/digital twins, legal clauses) to their temporal mechanisms (triggers, phase-gates, deadlines, sunsets, vesting, queue rules) and to institutional outcomes (budgetary sequences, permitting tempos, rights vesting). This grammar renders explicit what prior frameworks left implicit: resilience practices enrol sociotechnical imaginaries and administrative routines to stabilise some expectations while deferring or foreclosing others.

The contribution is not region-specific. Although motivating failures are often most visible where inequality, informality, and fragmented governance prevail, the inquiry is theoretical and comparative, oriented to second-order materials (published frameworks, guidance, and syntheses). The analytic unit is the mechanism, not the territory. By foregrounding multiscale assemblages and the circulation of devices, the approach responds to critiques of methodological cityism and enables comparison across contexts where hazard logics, planning instruments, and institutional time interact.

Prior research provides essential building blocks but stops short of an operator-level synthesis. Canonical frameworks organise city action yet remain under-specified on how instruments translate into temporal power. Deep-uncertainty methods introduce signposts, triggers, and branching pathways, but their distributive and juridical consequences are rarely theorised in urban governance terms. Justice-oriented planning cautions that procedures alone do not guarantee fair outcomes, yet it has not been systematically coupled to the temporal operators that move decisions. The present synthesis bridges these strands by treating temporal operators as the hinge between instruments and distributional effects.

Methodologically, the reconceptualisation is grounded in a PRISMA-guided corpus (2010–2025) and two-wave coding (pilot → full corpus) that extracted, for each study, its conceptualisation, devices, and temporal operators. Figure 2 documents the coding schema and summary statistics, while Supplementary S1 details screening logic and included sources. Read against the Results, the evidence shows that mainstream framings privilege equilibrium metaphors and hazard dashboards while under-specifying sequence, cadence, and distribution—the very features through which instruments exercise temporal power.

Substantively, three strands commonly treated separately are integrated. First, social–ecological co-evolution is understood as a field of contestation: resilience emerges from negotiated routines of repair, reciprocity, and mutual support (“care as resilience”), not solely from infrastructure hardening. Second, multi-scale governance is rendered as translation across subsystems (planning → law → finance): instruments vest rights, throttle permitting, and sequence budgets; equity hinges on how these translations distribute time (e.g., time-to-first-benefit, cadence variance, queue parity, participatory lead-time), formalised as auditable indicators. Third, ontological multiplicity is operationalised via temporal operators: when triggers and sunset clauses are tied to parity tests *ex ante*, transformation becomes a governed pathway rather than an accidental outcome of crisis.

Accordingly, urban climate resilience is defined here as the unfolding potential of ecological, infrastructural,

institutional, and relational systems to perceive, seize, and renew under climate stress through inclusive, situated, and care-oriented processes that enable both function and justice over time. This definition functions as an implementation grammar. In practice, it entails embedding parity-constrained triggers and phase-gates into pathway roadmaps; linking dashboards and digital twins to equity-sensitive delay ledgers and participatory lead-time metrics; aligning legal and administrative clauses with distributional targets; and institutionalising plural knowledges so that community signposts carry procedural weight alongside modelled thresholds. Each element is evidenced in, and abstracted from, the 71-study corpus.

Interpreting the Results through this grammar clarifies why technical effectiveness alone does not guarantee equitable outcomes. Strategies with strong hazard-attenuation performance achieve earlier and broader benefits when paired with enabling governance that constrains deferral and allocates first access fairly; conversely, finance-heavy or data-intensive instruments tend to produce temporal peripheries unless bounded by explicit parity rules. These patterns explain the comparative results reported in Tables 2–3 and account for the observed covariance between institutional coupling and outcome distribution.

Three cross-cutting implications follow. First, informality and ordinary repair practices should be treated as mechanisms of adaptation rather than contextual noise: when care-based capacities are wired into planning routines, pathways diversify toward community-anchored and nature-based measures and deliver earlier benefits to marginalised groups. Second, finance and procurement rules allocate time as much as money: dashboard- and twin-mediated orchestration privileges data-rich districts unless parity conditions (e.g., queue parity, time-to-first-benefit caps) operate as binding gates. Third, participatory governance improves outcomes only when participatory outputs are institutionally consequential—when locally co-produced thresholds and priorities directly adjust schedules, budgets, and approval cycles.

The findings also clarify the coupling of adaptation and mitigation. Read as device-enabled productions of institutional time, both streams distribute acceleration and waiting with intertemporal stakes. Without parity constraints, aggregate efficiency can coexist with unequal waiting. Synchronising operators across devices—particularly for nature-based solutions with dual hazard and co-benefit profiles—reduces legitimacy erosion and displacement risks while advancing temporal justice.

Overall, the review identifies an operational gap between conceptual advances in resilience research and their translation into practice. The lack of longitudinal monitoring, standardised temporal indicators, and cadence-aware evaluation limits learning and recalibration, especially in

marginalised contexts. By organising evidence through a meso-level grammar (device → temporal mechanism → institutional outcome) and translating recurrent failure points into implementable levers, the article closes this gap without proposing another framework. Rather than optimising tools in isolation, it points to upgrading auditing cultures—from aggregate coverage to cadence-aware compliance and to embedding temporal parity constraints directly into pathway statutes, budget ordinances, and programme agreements.

The comparative evidence reviewed here suggests that resilience outcomes are closely linked to how planning instruments structure institutional time, rather than to the technical characteristics of measures alone. Where instruments explicitly encode temporal constraints—such as parity conditions on time-to-first-benefit or cadence variance—adaptation portfolios tend to deliver earlier and more evenly distributed benefits. Conversely, in the absence of such constraints, implementation trajectories often reproduce temporal inequalities, even where formal commitments to equity are present.

These patterns indicate that auditing and evaluation practices play a constitutive role in shaping adaptation pathways. Monitoring regimes focused exclusively on aggregate outputs obscure lead-time differentials and sequencing effects that are critical for distributive outcomes. By contrast, evidence from the corpus shows that governance arrangements capable of integrating participatory outputs into formal schedules and review cycles are associated with fewer delays and more diversified intervention portfolios. These implications are synthesised in Table 3, which translates recurrent failure points into implementable levers grounded in the reviewed evidence.

Declarations

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Author Contributions. V.K.: conceptualisation; literature search and screening; data extraction and coding; analysis and interpretation; figure/table design; drafting and revision; final approval.

References

- [1] Adam, B. *Timescapes of Modernity: The Environment and Invisible Hazards* (Routledge, 1998).
- [2] Adegun, O. B. Green infrastructure can improve the lives of slum dwellers in African cities. *Front. Sustain. Cities* 3, 621051 (2021).
- [3] Allmendinger, P. Towards a post-positivist typology of planning theory. *Plan. Theory* 1, 77–99 (2002).
- [4] Amidu, M., et al. Insulating highly vulnerable populations from global pandemics: The case of Ghanaian informal settlements. *Cities* 141, 104504 (2023).
- [5] Angelo, H. & Wachsmuth, D. Urbanizing urban political ecology: A critique of methodological cityism. *Int. J. Urban Reg. Res.* 39, 16–27 (2015).
- [6] Anguelovski, I. & Corbera, E. Integrating justice in nature-based solutions to avoid nature-enabled dispossession. *Ambio* 52, 45–53 (2023).
- [7] Angwaomadoko, E. A. The impact of climate change on global economic stability: Developing economic policies to manage climate risks. *Issues Econ. Bus.* 10, 1–37 (2024).
- [8] Arnell, N. W., et al. The global and regional impacts of climate change under RCP and SSP scenarios. *Environ. Res. Lett.* 14, 084046 (2019).
- [9] Atkinson, C. L. Informal settlements: A new understanding for governance and vulnerability study. *Urban Sci.* 8, 158 (2024).
- [10] Bahadur, A. & Tanner, T. Transformational resilience thinking. *Environ. Urban.* 26, 200–214 (2014).
- [11] Bahl, A., et al. Assessing the risk of climate-induced natural disasters using risk assessment models. *E3S Web Conf.* 581 (2024).
- [12] Bai, X., et al. Six research priorities for cities and climate change. *Nature* 555, 23–25 (2018).
- [13] Bauer, S. & Messner, D. Climate change threatens global development and international stability. *Briefing Paper 7/2007* (2007).
- [14] Beermann, M. Linking social theory and social-ecological systems: Latour, critical realism and resilience. *J. Environ. Policy Plann.* 13, 371–394 (2011).
- [15] Behrend, J. & Levin-Keitel, M. Planning as a scientific discipline? On the contested boundaries of planning research. *Plan. Theory* 18, 497–518 (2019).
- [16] Bento, V. A., Lima, D. C. A. & Russo, A. Assessing climate-related risks: Heatwaves, droughts, fires, and pollution in vulnerable regions of the globe. *Copernicus Meetings* (2024).
- [17] Berkes, F. *Sacred Ecology* (4th ed., Routledge, 2018).
- [18] Berkes, F., Colding, J. & Folke, C. (eds) *Navigating Social–Ecological Systems: Building Resilience for Complexity and Change* (Cambridge Univ. Press, 2003).
- [19] Berntell, E., et al. Complex emergencies: Drivers of the humanitarian impacts of climate-related disasters. *Copernicus Meetings* (2024).
- [20] Berrisford, S. & Parnell, S. *Young Cities and the Climate Challenge: Building Resilience in Rapidly Urbanising Regions* (African Centre for Cities, 2021).
- [21] Bitting, C. D., Atangana, B. D. N. & Ngoa Tabi, H. Climate change vulnerability and sustainable urbanisation in Sub-Saharan Africa. *J. Sustain. Dev.* 15 (2022).
- [22] Boom Cárcamo, D., Anaya Cuello, K. & Boom Cárcamo, E. Violation of economic, social, cultural, and environmental rights among displaced women. *Violence Against Women* (2024).
- [23] Bryant, B. P. & Lempert, R. J. Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. *Technol. Forecast. Soc. Change* 77, 34–49 (2010).
- [24] Bügelmayer Blaschek, M., Millonig, A. & Zach, M. Climate mitigation pathways for cities—enabling a just transition through quantified actions? *Copernicus Meetings* (2024).
- [25] Buskop, F. E., Sperna Weiland, F. & van den Hurk, B. Amplifying exploration of regional climate risks. *Environ. Res.: Climate* 3, 045030 (2024).
- [26] Camacho, R., Aryal, J. & Rajabifard, A. Disaster-induced disruption of policies for informal urban settlements. *Cities* 150, 105098 (2024).
- [27] Carmin, J., Roberts, D. & Anguelovski, I. Planning climate resilient cities: Early lessons. *Fifth Urban Research Symposium* (2009).
- [28] Carmin, J., Roberts, D. & Anguelovski, I. Planning Climate Resilient Cities: Early Lessons from Early Adopters (World Bank, 2011).
- [29] Cartwright, E. D. Wildfires, record heat waves and extreme weather events—The perils of climate change. *Climate Energy* 41, 17–21 (2024).
- [30] Carvalho, P. & Spataru, C. Co-designing a just resilience balance scorecard. *Clim. Risk Manag.* 43, 100577 (2024).
- [31] Charak, A., Ravi, K. & Verma, A. Climate change—exacerbated natural hazards in India and socioeconomic vulnerabilities. *IDRiM J.* 13, 142–177 (2024).
- [32] Chen, S. & Zhao, G. A review of literature on ‘participatory governance’. *Teaching Res.* 8, 75–82 (2009).
- [33] Corburn, J., et al. Urban climate justice, human health, and citizen science in Nairobi’s informal settlements. *Urban Sci.* 6, 36 (2022).
- [34] Cousins, J. J. Just nature-based solutions and the pursuit of climate-resilient urban development. *Landsc. Urban Plan.* 247, 105054 (2024).
- [35] Crosson, C. Nature-based adaptation in a Nairobi informal settlement. In *World Congress of Architects* (Springer, 2023).
- [36] Davidson, K., et al. Interrogating urban climate adaptation: Toward a politics of transformations. *Urban Stud.* 53, 1765–1783 (2016).
- [37] Davoudi, S. Planning as practice of knowing. *Plann. Theory* 14, 316–331 (2015).
- [38] Davoudi, S. Resilience: A bridging concept or a dead end? *Plann. Theory Pract.* 13, 299–307 (2012).
- [39] Dessai, S. & Hulme, M. Assessing the robustness of adaptation decisions to climate change uncertainties. *Clim. Change* 64, 279–301 (2004).
- [40] Dey, R. & Lewis, S. C. Natural disasters linked to climate change. In *The Impacts of Climate Change 177–193* (Elsevier, 2021).
- [41] Di Ruocco, A., Gasparini, P. & Weets, G. Urbanisation and climate change in Africa. In *Urban Vulnerability and Climate Change in Africa 1–35* (2015).

- [42] Diep, L., et al. Co-building trust in urban nature via participatory NBS in informal settlements. *Front. Sustain. Cities* 4, 927723 (2022).
- [43] Fainstein, S. S. *The Just City* (Cornell Univ. Press, 2010).
- [44] Fohlmeister, S., et al. The way forward: Climate resilient cities for Africa's future. In *Urban Vulnerability and Climate Change in Africa* 369–399 (2015).
- [45] Folke, C. Resilience: The emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Change* 16, 253–267 (2006).
- [46] Fransen, J., Hati, B., van Stapele, N., Kiriro, S. & Nyumba, R. Resilience pathways of informal settlements in Nairobi. *Eur. J. Dev. Res.* 36, 355–380 (2024).
- [47] Friesen, J. & Delger, O. Spatial accessibility to hospitals for informal settlement dwellers. In *2023 Joint Urban Remote Sensing Event (JURSE)* (IEEE, 2023).
- [48] Frisch, L. Evaluating the Effectiveness of Green Infrastructure in Urban Resilience: A Case Study of Nairobi. Master's thesis (Technische Univ. München, 2019).
- [49] Garai, J. & Hok-Bun, K. Indigenous knowledge, climate adaptation and epistemic justice. *Environ. Sci. Policy* 154, 103–112 (2024).
- [50] Garschagen, M. & Marks, D. Risks, knowledge and power: Decision-making on climate change in Vietnam and Thailand. *Glob. Environ. Change* 58, 101939 (2019).
- [51] González, J. E., et al. Urban climate and resiliency: State of the art and future directions. *Urban Climate* 38, 100858 (2021).
- [52] Guillo, B., et al. Multi-hazard risk indicators for climate risk reporting. *Copernicus Meetings* (2024).
- [53] Gunderson, L. H. & Holling, C. S. (eds) *Panarchy: Understanding Transformations in Human and Natural Systems* (Island Press, 2002).
- [54] Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Change* 23, 485–498 (2013).
- [55] Haddad, B., Smit, M. & Kelly, E. Integrating resilience into urban planning: A socio-ecological perspective. *J. Urban Plann. Dev.* 148, 123–138 (2022).
- [56] Herslund, L. B., et al. A multidimensional assessment of urban vulnerability in Sub-Saharan Africa. *Nat. Hazards* 82, 149–172 (2016).
- [57] Herslund, L., et al. Towards climate change resilient cities in Africa. In *Urban Vulnerability and Climate Change in Africa* 319–348 (2015).
- [58] Holling, C. S. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4, 1–23 (1973).
- [59] Horn, P. Enabling participatory planning in exclusionary environments: Nairobi's Mukuru SPA. *Environ. Urban.* 33, 519–538 (2021).
- [60] Horn, P., et al. Towards citywide participatory planning: Emerging community-led practices in three African cities. Working Paper 34 (Global Development Institute, 2018).
- [61] Huq, E. Green informalities as socially just ecological infrastructure: Dhaka. *Int. J. Urban Reg. Res.* 48, 560–583 (2024).
- [62] Hutter, G. & Wiechmann, T. Time, temporality and planning: Comments on the state of the art in strategic spatial planning research. *Raumforsch. Raumordn. Spatial Res. Plann.* 79, 1–14 (2021).
- [63] IPCC. *Climate Change 2023: Synthesis Report* (IPCC, 2023).
- [64] Ivanova, A., et al. Climate hazards and human migration: Literature review. *Environ. Res.: Climate* (2024).
- [65] Jasanoff, S. & Kim, S.-H. (eds) *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power* (Univ. Chicago Press, 2015).
- [66] Jimoh, S. O., et al. Informal sector and financial development in Sub-Saharan Africa. *Int. J. Econ. Manag. Account.* 31, 325–342 (2023).
- [67] Kamjou, M., Scott, M. & Lennon, M. Governing nature-based solutions in informal settlements: Maintenance, tenure and justice. *Environ. Urban.* 36, 87–104 (2024).
- [68] Kang, P., Chen, W., Hou, Y., & Li, Y. Spatial-temporal risk assessment of urbanisation impacts. *Sci. Rep.* 9, 16806 (2019).
- [69] Karanja, F. N. & Mwangi, M. T. Sustainable urban development and resilience in Nairobi. *Afr. J. Land Policy Geospat. Sci.* 5, 85–102 (2016).
- [70] Kariuki, P. B. Adaptation Strategies to Adverse Effects of Climate Variability on Water and Sanitation Access in Mukuru Kwa Njenga Slum, Nairobi County (2018).
- [71] Karuga, R., et al. Voices and challenges of marginalised groups in Nairobi. *Front. Public Health* 11, 1175326 (2023).
- [72] Keys, P. W., et al. Exposure to compound climate hazards via trade networks (2024).
- [73] Koasidis, K., et al. Climate and sustainability co-governance in Kenya: A multi-criteria analysis of stakeholder perceptions and consensus. *Energy Sustain. Dev.* 68, 457–471 (2022).
- [74] Kunze, A., et al. A conceptual participatory design framework for urban planning. In *Proc. eCAADe* 895–903 (2011).
- [75] Kwadijk, J. C. J., et al. Using adaptation tipping points to prepare for climate change and sea-level rise: A case study in the Netherlands. *Water Resour. Res.* 46, W10504 (2010).
- [76] Kweyu, R. M., et al. Climate governance in Eastern Africa. In *State Politics and Public Policy in Eastern Africa* 347–369 (2023).
- [77] Larsen, L. Urban climate and adaptation strategies. *Front. Ecol. Environ.* 13, 486–492 (2015).
- [78] Lawrence, J. & Haasnoot, M. What it took to catalyse, embed and mainstream dynamic adaptive pathways planning practice. *Climatic Change* 141, 615–628 (2017).
- [79] Leichenko, R. Climate change and urban resilience. *Curr. Opin. Environ. Sustain.* 3, 164–168 (2011).
- [80] Lempert, R. J., Popper, S. W. & Bankes, S. C. *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis* (RAND Corporation, 2003).
- [81] Locatelli, L., et al. Socio-economic assessment of green infrastructure for urban drainage planning. *Sustainability* 12, 3792 (2020).
- [82] Long, D. & Ziervogel, G. Vulnerability and adaptation in urban South Africa. In *Urban Geography in South Africa* (2020).

- [83] Loor, I. Informal green infrastructure and climate-responsive environments in Quito City. In *Governance of Climate Responsive Cities* 127–146 (Springer, 2021).
- [84] Lueong, L. A. Governance in implementing climate adaptation in the Congo Basin. *J. Geogr. Environ. Earth Sci. Int.* 28, 70–80 (2024).
- [85] Machuki, S. & McIntyre Mills, J. Participatory and inclusive governance in Nairobi's sustainable urban development. In *Balancing Individualism and Collectivism* 239–257 (2018).
- [86] Maes, M. J. A., et al. Monitoring exposure to climate-related hazards: Indicator methodology and key results (2022).
- [87] Maihack, H. Contested Urban Citizenship in Kenya (Nomos, 2023).
- [88] Martin, R., Sunley, P., Gardiner, B. & Tyler, P. How regions react to recessions: Resilience and the role of economic structure. *Reg. Stud.* 50, 561–585 (2016).
- [89] Massey, D. Politics and space/time. *New Left Rev.* 196, 65–84 (1992).
- [90] Matyas, D. & Pelling, M. Positioning resilience for 2015: The role of resistance, incremental adjustment and transformation in disaster risk management. *Disasters* 39, S1–S18 (2015).
- [91] Mayar, K., Carmichael, D. G. & Shen, X. Resilience and systems—A building structure case example. *Buildings* 13, 1520 (2023).
- [92] McBean, G. & Rodgers, C. Climate hazards and disasters: The need for capacity building. *WIREs Clim. Change* 1, 871–884 (2010).
- [93] McCann, E. Framing space and time in the city: Urban policy and the politics of spatial and temporal scale. *J. Urban Aff.* 25, 91–105 (2003).
- [94] McGuire, B. *Geophysical and Climate Hazards: A Very Short Introduction* (Oxford Univ. Press, 2024).
- [95] Meerow, S., Newell, J. P. & Stults, M. Defining urban resilience: A review. *Landsc. Urban Plan.* 147, 38–49 (2016).
- [96] Méjean, A., et al. Climate change impacts increase economic inequality: A systematic review. *Environ. Res. Lett.* (2024).
- [97] Mikulewicz, M. Politicizing vulnerability and resilience: A critique of climate change adaptation policy. *Geoforum* 104, 111–120 (2019).
- [98] Miller, C. A. Climate dashboards, data politics and the governance of anticipation. *Sci. Technol. Stud.* 33, 2–22 (2020).
- [99] Miraftab, F. Insurgency, planning and the prospect of a humane urbanism. *Rev. Bras. Estud. Urbanos Reg.* 18, 363–377 (2016).
- [100] Mirtaheri, P. & Pugliese, A. Artificial intelligence for climate risk modelling in cities. *Sustain. Cities Soc.* 104, 105214 (2024).
- [101] Molenveld, A., van Buuren, A. & Ellen, G. J. Governance of climate adaptation—Which mode? *Climatic Change* 162, 233–254 (2020).
- [102] Morison, S. J. *Participatory Governance, Sprawl, and Sustainability in Gatineau, Quebec*. PhD thesis (Univ. British Columbia, 2011).
- [103] Muchiri, C. N. & Opiyo, R. O. Community adaptation strategies in Nairobi informal settlements. *Front. Sustain. Cities* 4, 932046 (2022).
- [104] Munene, M. B. *Urban Resilience in Nairobi*. Master's thesis (King's College London, 2016).
- [105] Mutuku, S. W. & Irungu, T. Urban green infrastructure mitigating climate risks in Nairobi. *Sustainability* 14, 4431 (2022).
- [106] Mwanzu, J., et al. Urban riparian restoration and flood resilience in East African cities. *J. Environ. Manage.* 345, 118612 (2023).
- [107] Nunn, P. D. Climate change, time and transformation. *Reg. Environ. Change* 24, 19 (2024).
- [108] Nunn, P. D., Smith, R. & Elrick-Barr, C. Institutional time, climate risk and delayed adaptation. *Clim. Policy* 21, 1256–1269 (2021).
- [109] Nyaundi, C. M. & Obade, P. T. Contribution of civil society in climate change adaptation in Nairobi City County. *Int. J. Life Sci. Agric. Res.* 2, 393–400 (2023).
- [110] Nyika, J. & Dinka, M. O. Urban resilience to the challenges of climate change: The case of Africa. In *Sustainable Urbanism in Developing Countries* 263–275 (CRC Press, 2022).
- [111] Nyika, J. Climate change in Kenya and adaptive management in the water sector. In *Research Anthology on Environmental and Societal Impacts of Climate Change 1857–1872* (IGI Global, 2022).
- [112] O'Neill, P. F. Building resilience through risk analysis. In *Resilience and Risk* 451–468 (Springer, 2017).
- [113] Ogutu, F. A., Kimata, D. M. & Kweyu, R. A. A critique on sustainable cities waste management: Nairobi City. *J. Appl. Sci. Environ. Manag.* 24, 1801–1810 (2020).
- [114] Oloitipiti, F. R., Ndunda, E. & Gichuki, C. M. Adaptation strategies by suburban pastoralists in Nairobi interface. *Pastoralism* 13, 6 (2024).
- [115] Pandey, V. K., Anshu & Sharma, K. K. Climate change adaptation policies and governance: A critical appraisal. In *Climate Change and Human Adaptation in India* 199–206 (Springer, 2024).
- [116] Pauleit, S., et al. Urban vulnerability and climate change in Africa. *Future City* 4 (2015).
- [117] Pede, E. *Planning for Resilience: New Paths for Managing Uncertainty* (Springer, 2020).
- [118] Pelling, M. *Adaptation to Climate Change: From Resilience to Transformation* (Routledge, 2011).
- [119] Preston, B. L., et al. Practical approaches to assessing climate change vulnerability. *Clim. Change* 100, 461–487 (2010).
- [120] Puig de la Bellacasa, M. *Matters of Care* (Univ. Minnesota Press, 2017).
- [121] Rodríguez, M. B. & Urdaneta Troconis, C. Vulnerabilidad y políticas para asentamientos informales: El Hatillo, Venezuela. *Bitácora Urbano/Territorial* 34 (2024).
- [122] Rotich, S. J., Funder, M. & Marani, M. Suburban pastoralists at the rural–urban interface. *Pastoralism* 13, 6 (2023).
- [123] Roy, A. Urban informality: Toward an epistemology of planning. *J. Am. Plan. Assoc.* 71, 147–158 (2005).
- [124] Roy, M. & Berke, P. Social equity, land use planning, and flood mitigation. *Oxford Res. Encycl. Environ. Sci.* 822 (2022).
- [125] Ruth, M. (ed.) *Distributional Impacts of Climate Change and Disasters: Concepts and Cases* (Edward Elgar, 2009).

- [126] Ruth, O., Lagat, D. & Lilian, O. Linking adaptation and mitigation toward resilient infrastructure in Kenya. In *African Handbook of Climate Change Adaptation* (2020).
- [127] Schmidt, R. & Awuor, C. B. Urban adaptation to climate change in Nairobi. *Policy Insights Environ. Vision* 45, 54–70 (2020).
- [128] Sharifi, A. & Yamagata, Y. Resilience-oriented urban planning. In *Resilience-Oriented Urban Planning: Theoretical and Empirical Insights* 3–27 (2018).
- [129] Sharma, A. & Tompkins, E. L. Climate change adaptation and resilience in urban systems. *WIREs Clim. Change* 11, e635 (2020).
- [130] Shi, L. Beyond flood risk reduction: How can green infrastructure advance justice and regional impact? *Socio Ecol. Pract. Res.* 2, 311–320 (2020).
- [131] Simone, A. M. *For the City Yet to Come: Changing African Life in Four Cities* (Duke Univ. Press, 2004).
- [132] Smedley, T. *Solved: How the World's Great Cities Are Fixing the Climate Crisis* (Univ. Toronto Press, 2019).
- [133] Song, X., et al. A systematic review of the inequality of health burdens related to climate change. *Front. Environ. Sci. Eng.* 18, 63 (2024).
- [134] Sørensen, E. New Institutionalism in Planning Theory. In *The Routledge Handbook of Planning Theory*, ch. 20 (Routledge, 2017).
- [135] Tozer, L., et al. Towards just nature-based solutions for cities. In *Nature-Based Solutions for Cities* 30–47 (Edward Elgar, 2023).
- [136] Tronto, J. C. *Moral Boundaries: A Political Argument for an Ethic of Care* (Routledge, 1993).
- [137] Tyler, S. & Moench, M. A framework for urban climate resilience. *Clim. Dev.* 4, 311–326 (2012).
- [138] UN-Habitat. *Participatory Slum Upgrading: Participatory Enumeration and Mapping Toolkit* (UN-Habitat, 2010).
- [139] United Nations Office for Disaster Risk Reduction (UNDRR). *Disaster Resilience Scorecard for Cities: Detailed Level Assessment* (2017; rev. 2019).
- [140] Van Assche, K. & Verschraegen, G. The limits of planning: Niklas Luhmann's systems theory and the analysis of planning and planning ambitions. *Plann. Theory* 7, 263–283 (2008).
- [141] Van Leeuwen, C., et al. Climate change impacts and adaptations of wine production. *Nat. Rev. Earth Environ.* 5, 258–275 (2024).
- [142] wa Teresia, J. N. Awareness, attitudes, and perceptions of safety among slum residents in Nairobi. *East Afr. J. Arts Soc. Sci.* 5, 154–173 (2022).
- [143] Waigwa, G. M. Gender, participation and climate adaptation in informal settlements. *Gender Place Cult.* 30, 1123–1141 (2023).
- [144] Walker, B., Holling, C. S., Carpenter, S. R. & Kinzig, A. Resilience, adaptability and transformability in social–ecological systems. *Ecol. Soc.* 9, 5 (2004).
- [145] Wardekker, W. Contrasting the framing of urban climate resilience. *Sustain. Cities Soc.* 75, 103258 (2021).
- [146] Whyte, K. P. Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. *Engag. Sci. Technol. Soc.* 3, 153–162 (2017).
- [147] Yadav, M., et al. Climate change and global inequality. In *Effects of Climate Change on Social and Economic Factors* 21–48 (IGI Global, 2025).
- [148] Yiftachel, O. Towards a new typology of urban planning theories. *Environ. Plann. B* 16, 23–39 (1989).
- [149] Zhu, B. & Fuerst, F. Climate hazard exposure increases systematic risk. *SSRN* (2024).
- [150] Zohuri, B., et al. Resilience and resilience system. In *Business Resilience System (BRS)* (2017).

Tables and figures

Figure 1. PRISMA diagramⁱ

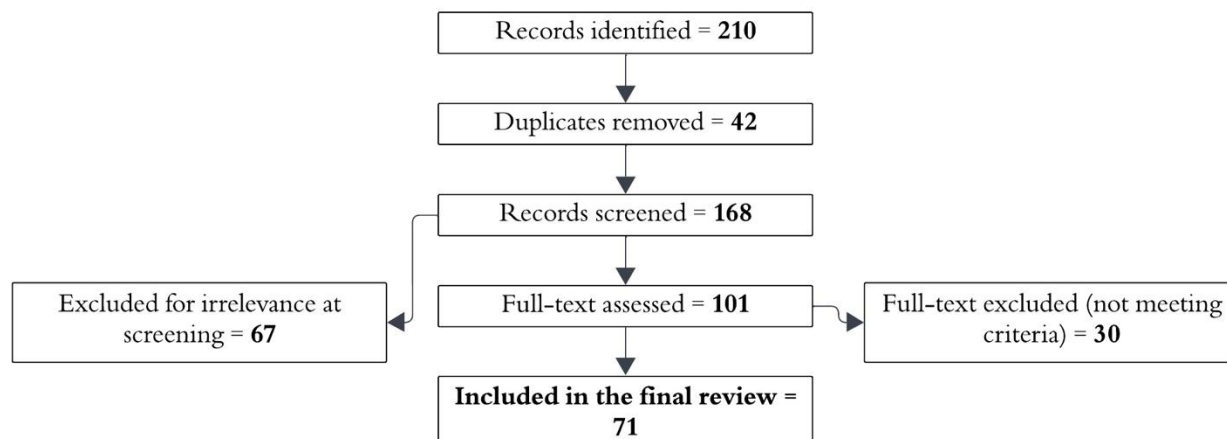


Figure 2. Coding system diagramⁱⁱ

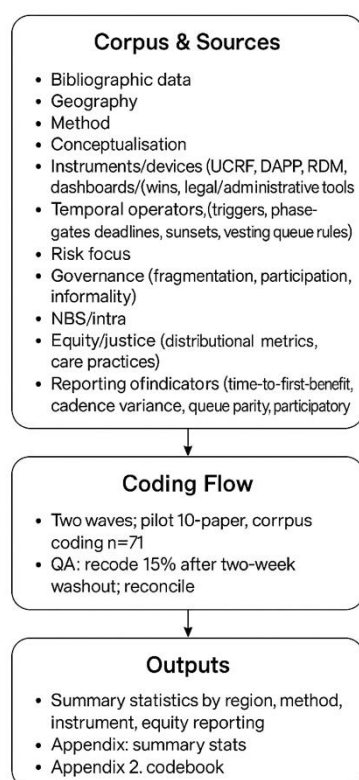


Figure 3. Classical approaches to defining Urban Climate Resilienceⁱⁱⁱ

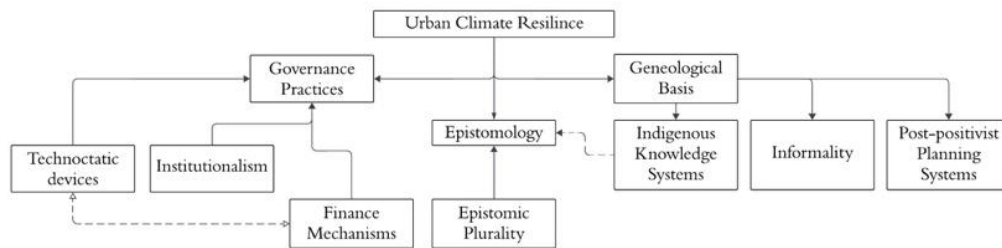


Table 1. Climate Resilience Analytical Tools Comparison^{iv}

Criteria	CRI	UCRF
Focus area	Infrastructure; social cohesion; institutional effectiveness	Governance; land-use; resource management
Strengths	Multidimensional Perspective; Cross-Regional Comparisons	Participatory Approach
Limitations	Aggregated Data May Oversimplify Localized Vulnerabilities; Less Effective In Rural Areas	Urban-Centric Focus
Challenges in application	Limited data availability	May not account for decentralized decision-making

Table 2. Comparison of Climate Resilience Strategies^v

Resilience Strategy	Effectiveness	Challenges
Green infrastructure	High	High cost, land-use conflicts
Participatory governance	Medium-high	Political resistance, coordination issues
Early warning systems	High	Lack of infrastructure in low-income areas
Climate finance mechanisms	Medium	Inequitable funding distribution

Table 3. Design for Implementation^{vi}

Key Finding	Practical Application	Example Tool / Approach
Marginalization of informal settlements	Prioritize slum upgrading in adaptation plans	UN-HABITAT participatory mapping
Lack of longitudinal studies	Implement resilience monitoring systems	Urban resilience scorecard (UNDRR)
Exclusion of local knowledge	Institutionalize community-based adaptation processes	Participatory scenario workshops
Fragmented governance	Foster multi-level urban climate committees	Resilience offices or task forces

Endnotes

- ⁱ Author's own diagram. Counts derive from the screening workflow reported in Methods and Supplementary Table S1; layout follows standard PRISMA reporting conventions (PRISMA 2020).
- ⁱⁱ Author's own design, informed by core resilience/governance frameworks [96, 56, 90, 98, 37, 38, 39] and justice/equity literatures [3, 26, 91, 94]; indicator/monitoring guidance [61, 35].
- ⁱⁱⁱ Author's conceptual synthesis drawing on ecological and social-ecological foundations [40, 11], urban/planning syntheses [96, 56, 90, 98], critiques and care ethics [91, 3, 26, 94, 95, 83], and planning theory [101]
- ^{iv} Author's own comparative summary of CRI/UCRF and related instruments, drawing on framework expositions and assessment work [96, 98, 37, 38, 39, 57, 35].
- ^v Author's evidence synthesis. Effectiveness/constraints distilled from NBS/green-infrastructure studies [1, 26, 43, 73, 29, 94, 57, 81]; governance/participation [41, 42, 69, 51]; hazard/EWS and exposure monitoring [28, 65, 61]; equity/finance/inequality and informality [67, 25, 32, 71].
- ^{vi} Author's own design translation (device → temporal mechanism → institutional outcome). Example levers/tools adapted from participatory/UN-Habitat-style mapping and co-production [42, 54, 41], informality/just-NBS literatures [1, 43, 3, 26, 94], governance coordination [69, 51], and monitoring/scorecard guidance [61, 98].