Current indicators and metrics hinder effective urban climate adaptation

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Abstract

Assessing the effectiveness of climate adaptation action is the focus of intense debate across scientific and policy arenas. Measurement is essential for effective adaptation management and operation, and indicators and metrics (I&M) have a pivotal role. Surprisingly, there are very few systematic efforts to understand the advances in the provisioning of adaptation I&M. Here we analyse 137 publications and 901 I&M sourced in the scientific literature to measure adaptation to climate change, particularly, in urban areas where governments are increasingly placing efforts to prepare populations and infrastructures. A lack of common terminology, standardisation, and reference guidelines has resulted in a field that is complex to track and understand. Furthermore, such complexity has led to diverse, context-specific and sometimes competing approaches to developing I&M. We argue that current I&M proposals are highly technical, not sufficiently grounded on real needs, and have little potential to collectively support effective urban climate change adaptation.

Introduction

While tracking emission pledges dominates recurrently in international conversations[1], the evaluation of progress on climate change adaptation has also become a hot topic across scientific and policy arenas, and at multiple levels of governance. Measuring adaptation progress is essential for understanding adaptation needs, accounting for actions, and assessing their effectiveness and efficiency[2]. Measuring is also important to evaluate positive and negative impacts and the equity of adaptation actions[3]. Measuring helps learning and improves future adaptation processes allowing for comparisons and benchmarking. Finally, it helps attract political momentum and funding, as well as to understand the relationship of adaptation with other societal, climate or biodiversity challenges [4–6]. The conceptual and empirical literature is vast, scattered and difficult to track for many reasons. First, there is an ambiguous use of language when it comes to adaptation - e.g. interchangeably using “climate resilience,” “climate adaptation,” “climate vulnerability” or risk reduction” to refer to states of better preparedness and unclear connections with adaptation monitoring, evaluation, reporting, and learning (MERL) objectives and stages. Second, while attempts have been made[7–10], shared frameworks for research and practice are lacking. Much attention is being directed to identifying ways to measure progress towards the Global Goal on Adaptation[11,12], however, up to now, there is no good understanding of the progress in the field of adaptation measurement across scales and sectors.

As a result of the context-specific nature of adaptation needs and the absence of universal effects from adaptation actions, the field of adaptation measurement has moved forward under risky assumptions. For urban adaptation, for instance, the accountability and quality assessment of adaptation plans and policies have typically been used as proxies for progress[13–16] overlooking their symbolic dimension[17] and lack of financing or implementation[18]. The scant attention to indicators and metrics (I&M) has largely been theoretical or too context- or sector-specific [9,19–24]. Few studies have comprehensively and systematically analysed the state of the art of urban climate change adaptation I&M. Arnott et al.[8]

provided an analysis of 43 urban adaptation I&M documents gathered from grey literature developed by governments, boundary organisations and sponsors. Salehi et al. [23] performed a systematic review and extracted 176 adaptation I&M from 59 sources, mainly scientific literature. None of these studies performed a detailed analysis of the types, characteristics, and applicability of collected I&M.

In this paper, we systematically review and analyse the vast and scattered scientific literature regarding I&M to assess adaptation to climate change in urban areas, where governments around the globe are increasingly efforts to prepare populations and infrastructures for the impacts of climate change through plans and policies. This is a pioneering effort that has been designed to understand four key aspects: (i) the nature and geography of existing empirical research work (ii) the typology of climate impacts and adaptations covered (iii) the landscape of I&M currently proposed, and, (iv) their intended users and uses. We focus on I&M specifically targeted to measure urban climate change adaptation. We systematically identify 838 publications from the openly accessible and multi-sourced LENS database. Across a set of 137 publications capturing indicators that measure climate change adaptation in urban areas (see Supplementary Materials for the specific criteria, Table SM1), we collect and examine 901 I&M (including indices). Publications are dated from 2007 until 2022, with 70% published after 2016, coinciding with an increased focus on I&M after the Paris Agreement in 2015.

Results

Geography of the studies

The vast majority of studies are empirical (95% of 137). Few studies are conceptual/theoretical (4%) or review works (1%). The empirical body of work focuses on specific geographic regions and cities and discusses the applicability of proposed indicators. Most I&M are applied in Asian (42%) and European (31%) cities followed by North American (16%), Latin American (12%), African (11%) and Oceanian (5%) (see Fig. 1a). In a few cases (9%), cities from different world regions are looked at in combination, but the application of I&M is addressed generally with regional exclusivity. Studies encompass a diversity of spatial scales, from the supralocal to the household level. Many proposed I&M are not specific to any one scale. A substantial majority (72%) mention addressing the city as a whole. Twenty-five percent of studies mention addressing scales beyond the city level while still assessing urban adaptation interventions (peri-urban, urban agglomerations, metropolitan and supralocal) and 29% of studies focused on scales often below the city level, including district, neighbourhood, and household or community level (Fig. 1b).

Type of assessments and methods

Generally, I&M are used in formative assessments (i.e. to understand baseline conditions and vulnerabilities) or in summative assessments (i.e. understand effectiveness, efficiency, and performance)[25]. A significant share of our sample (72%) (Fig. 1c) adopts a formative approach, where I&M are used to identify specific sectors, populations, or spatial areas where adaptation capacities need

to be built or increased. The literature, however, is often ambiguous regarding whether and how this assessment of adaptation needs (often through mapping the evolution of vulnerabilities, risks or adaptive capacities) will be connected to MERL processes. Alternatively, summative studies (28%) look into the assessment of implemented adaptations and propose I&M to monitor, evaluate, report, and learn from specific urban adaptation processes and actions on the ground.

To build I&M, quantitative (46%) and mixed methods (44%), such as survey data analysis, statistical analysis, and data modelling, are predominant across empirical studies, both for formative and summative assessments (Fig. 1c). The use of qualitative approaches like in-depth interviews, focus group discussions, case studies, thematic analysis, observations, and content analysis to build I&M is less common (10%).

Disciplines and theoretical frameworks behind I&M

Technical areas such as environmental sciences, climate and meteorology (26%), engineering and technology (23%) and urban planning, design, management and architecture (20%) (Fig. 2a) address urban adaptation I&M more frequently. By contrast, we found less prevalence of social science and interdisciplinary areas such as geography (15%), economics (5%), political science, law and sociology (11%) and disaster risk management (7%).

Around 44% of the studies do not mention any theoretical background or model used to guide or frame the proposal of urban adaptation I&M. The studies that identify a theoretical framework show a massive degree of dispersion (Fig. 2b). The most common approach used across studies is disaster risk management (12%), adaptive capacity assessments (7%), climate modelling and simulation approaches (7%), socio-ecological resilience theory (9%) and climate risk-based approaches (7%) follow closely. None of the studies referred to specific MERL frameworks [7,8,10,20].

Target users

The primary audience or target users of the study are rarely explicitly mentioned or justified. Despite this ambiguity, we infer from our analysis that local authorities (71% of the studies), urban planners and designers (59%) and the scientific community (43%) are predominantly the intended recipients of the studies (Fig. 2c). Regional or national governmental bodies follow closely (24%). Other local actors such as citizens (12%), non-governmental organisations (NGO) or advocacy groups (5%), financial actors (4%), private companies (4%), or international city networks (3%) are only occasionally considered as users for urban adaptation I&M.

Types of hazards and adaptations

In line with global urban adaptation responses[2], our review reveals that the most frequently considered hazard is rain/river flooding (43%), followed by storm/coast flooding (32%) and heatwaves (23%), with less attention paid to water security (20%) and food security (7%) (Fig. 2d). The I&M studies in our sample look at a wide range of adaptation measures. The most popular are land-use planning (32%),

flood management (30%), water and sanitation (29%), and livelihoods and social protection (28%) (Fig. 2e). The least focused on are education and communication (9%), air quality regulation (7%), food production and security (4%), information, communication and technology (ICT) (2%) energy infrastructures (7%) and transport (8%). Among the IPCC categories[26], only cultural heritage and institutions gather zero attention.

Types of Indicators and Metrics (I&M)

We gathered 901 I&M from 137 studies and distinguish between single I&M and composite I&M (typically, indices composed of more than one indicator or metric). Only 15% of the I&M are classified as indices (e.g. "Adaptive Capacity Index," "Integrated Urban Resilience Index" or "Heat Vulnerability Index"). The remaining are classified as single I&M, for example, "Percent Green Open Space," "Diversity of Renewable Energy," and "Increased Flood Insurance Coverage". We analyse the indices in their composite form. We also distinguish two categories of I&M depending on their tangibility: indicators and metrics[8]. While indicators can be general and unspecific (e.g. population vulnerability), metrics represent more detailed tangible measurements (e.g. number of trees). Concurring with previous studies[9], a significant majority of I&M (73%) are identified as "indicators", encompassing both single and composite forms. The remaining 27% are expressed as "metrics", encompassing only single forms (Fig. 3).

We further categorise I&M into four types: input, output, outcome, and impact[7,9,27]. The level of inputs (41%) suggests a strong emphasis on measuring resources and efforts allocated for climate adaptation processes. Outputs (22%) capture the tangible products and services resulting from adaptation efforts. The focus on outcomes (28%) reflects the relative importance placed on assessing the immediate results of adaptation strategies. Finally, the lower level of measured impacts (9%) indicates a weak focus on or inability to measure the broader long-term consequences of urban climate adaptation interventions. When considering metrics alone, the share of inputs (57%) is even higher than outputs, outcomes and impacts (Fig. 3).

I&M vary between the dimensions they look at [9,24]. Our study finds the environmental/natural dimension (27%) to be most prevalent (Fig. 3). This dimension encompasses a wide range of critical environmental variables, including green or blue space, climate impacts, sequestration capabilities, flooding, and biodiversity-related variables. The social/human/society dimension (23%) includes aspects such as knowledge, perception, community preparedness, or educational activities. Built infrastructure (22%) looks at resilient urban structures, materials, properties, and other characteristics in urban climate adaptation planning and design. The governance/institutional/policy dimension (14%) and the economic/finance dimension (13%) are less explored. Our data further shows that for single I&M, 80% encompass one dimension and 20% have two dimensions. The composite I&M are more multidimensional in nature (23% two dimensions, 11% three, 11% four, and 10% five). I&M are represented across all dimensions but progress indicators (outcomes and impacts) are more prevalent in the governance/institutional/political and social/human/society dimensions relative to process indicators (input and outputs) (Fig. 3).

Applicability and feasibility of urban adaptation I&M

In 75% of the cases, I&M are not connected with specific adaptation measures regardless of the composite nature of the I&M or its level of detail (indicator or metric). Our analyses show that the applicability of the I&M continues to be most prevalent at the city level (52%) (Fig. 4). The supralocal, household, and community levels receive less attention (1% or less respectively) with none at the metropolitan or urban agglomeration scales. The remaining efforts focus on the neighbourhood (21%) and district (16%) levels. In 10% of cases, the scale to which the I&M is applicable is not clearly defined.

A large majority of I&M are based on historical and statistical data (29%), followed by spatial data and field observations (21%) interviews and focus groups (16%), surveys (15%) and expert and literature data (8%) (Fig. 3b). The source is not specified in only 12% of cases. Our data also shows that, in around 48% of the cases, the I&M lack a specified unit of measurement. The units of measurement include percentages of some criteria (26%); length, area, or volume (18%); or binary data (i.e. yes or no) (13%). Higher levels of detail imply higher feasibility in application. While 97% of the metrics have an associated unit of measurement, only 35% of the indicators do. Types of I&M have varying levels of associated units of measurement: outputs (62%), outcomes (48%), inputs (53%), and impacts (37%). For I&M looking at governance/institutional/political aspects, only 33% specify units of measurement, in contrast to I&M looking at economic/finance aspects (59%). From the I&M that have associated units of measurement, only 3% specified the required frequency of measurement (80% of which are measured annually).

Finally, we also collect information regarding the purposes behind measuring adaptation for each I&M (Fig. 3c). This information is often ambiguous and requires an interpretation by the analyst. For sets of I&M, this information is normally very similar but not always the same. In most cases (27%), the collected data can potentially be used to assess adaptation needs and their dynamics/evolution. Other purposes include evaluating the results of adaptation actions (outcomes and impacts) (19%), improving future adaptation activities or interventions (15%), and assessing the efficiency and effectiveness of adaptation efforts and processes (13%). Less attention is paid to other important reasons to measure the progress of adaptation, such as comparing with other similar adaptation activities or interventions (2%), attracting funding and distributing resources (1%), gathering political momentum (0.4%), or increasing understanding of adaptation and its relationship with other societal challenges (5%).

Discussion

Our exercise has proven that extracting detailed data on I&M for the assessment of urban adaptation to climate change from the scientific literature is a complex enterprise. First, the language used in this field is often ambiguous and used lightly. For example, the terms indicator and metric are often used in the absence of a concrete form of measurement[8]. The same applies to references of adaptation “evaluation,” “measurement,” and “assessment” that often, do not refer to an analytical process to determine the results of an adaptation action. Secondly, we have observed a lack of clarity when it comes to explaining the theoretical framework and application of I&M. The definition of adaptation I&M, both in science and

policy, requires a conceptual framework that, not only provides guidance and a theory of change but also a shared language[20]. Our results, however, show a lack of conceptual basis for I&M that could be traced back to a lack of theoretical underpinning in social vulnerability, resilience, and adaptation research[29]. Arguably, this might be the reason why we find such a complex body of literature that is difficult to track, understand, and apply.

One key consequence of the absence of shared theories and terminologies in the adaptation I&M field is a weak potential to standardise MERL frameworks, indicators, and targets for assessing climate adaptation. While there is a popular tendency to promote the benefits of standardised I&M, scholars also warn about the negative consequences of overlooking the political context in the process of standardisation[25]. Our review shows that there is an immense diversity of I&M used to measure adaptation efforts at the urban level alone. This diversity reflects the context-specific nature of adaptation, but it also creates difficulties for comparability, benchmarking, reporting and ultimately, effective adaptation planning, implementation and management. Moreover, it may overwhelm the limited resources of local authorities who have to deal with a large number of indicators in their broader sustainability assessment efforts[26].

This systematic review shows empirical work concentrated at the city scale and in European and Asian countries and calls for further studies at scales below the city level and greater global scope. Our review also shows stronger attention to floods and heatwaves, which likely connects to the greater emphasis on adaptations in the sectors of land use, housing and urban planning, and flood and water management.

Beyond urban planning and geography, our data shows that expertise in social sciences is not leading work in the field. This brings into question whether the long-standing experience in MERL in political sciences and business management research areas has had a chance to influence this emergent field. It also questions whether and how critical social and economic aspects of vulnerability, equity and justice are being connected to approaches for monitoring and evaluation, and explains the lack of attention to these issues in current practice[3,30]. While quantitative works are more prevalent than qualitative ones, the use of mixed methods is an extended practice, which we interpret as a positive sign of interdisciplinarity.

Quantifiable variables to measure the success of adaptation measures are not common. Indicators (73%) are preferred over metrics (27%) for the evaluation of urban adaptation. The dominance of process-based I&M (inputs and outputs) could be connected to a greater focus on formative approaches across publications. While formative approaches positively indicate the recognition of adaptation as a process rather than only an end goal, attention to summative approaches is also required, to allow adaptation actors to understand the performance, efficiency, effectiveness, equitability and sustainability of adaptation interventions[9]. A longer-term view is also critical to cope with the uncertainty related to the impacts of climate change and adaptation ambiguities[31] and to plan for transformative adaptation and broader change[32]. However, the context-adjustment requirements and the mismatch between the timescale of an adaptation intervention and the time taken for the intervention results to become evident

is likely to be a challenge. This might be limiting the focus to process and short-term outcomes [15,33,34]. A general lack of measurement units highlights the need for accurate and reliable data interpretation, particularly for impact indicators and those related to governance and institutional aspects. While previous studies looking at policy documents[9] showed an abundance of governance I&M, we observe a lack of attention to governance/institutional/policy and economic/finance aspects in urban adaptation I&M literature.

In our study, we exclude publications looking at resilience or disaster risk reduction in general, however, we observe that the development of climate adaptation I&M is significantly influenced by their frameworks and models which demonstrates the need to bridge climate change, disaster, and resilience agendas[35]. Common local resilience assessment tools and frameworks display an abundance of I&M[36], which evidences the need for cross-examination and cross-fertilisation of resilience and adaptation MERL fields. Holistic approaches to capture multiple risks and interactions of different hazards are also lacking which calls for greater attention to cascading and compound effects of multiple hazards on urban systems and populations, beyond climate change[37].

The information regarding end-users and reasons for different measures is generally vague and ambiguous, questioning how usable the proposed urban adaptation I&M are in real-world contexts beyond academia. Overall, we observe a lack of attention to other reasons to measure adaptation beyond accountability and assessments of results. This calls for further theoretical and empirical developments that look at why adaptation measurement matters for equity, finance, politics, and other societal-, biodiversity-, and climate-related challenges.

Our work gathers evidence to build more robust guidance for designing, implementing and using adaptation I&M, particularly in urban areas. We have identified a range of knowledge gaps and needs that can inform other sectors and governance scales. Beyond scientific and technical use, this systematic effort has the potential to influence multi-level adaptation policy progress, as cities and other private and public organisations are increasingly working to strengthen their monitoring and evaluation systems in light of recent international climate adaptation policies and sustainable development goals.

Declarations

Data availability

Data generated or analysed during this study are included in this published article (and its Supplementary Information) and online repositories. The information available through online repositories includes the dataset of publications and indicators and connected metadata, which can be found online at DOI 10.5281/zenodo.10663610.

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Author contributions

MO Conceptualisation; Methodology; Data collection stage 1; Data collection stage 2; Data curation; Formal analysis; Writing- original draft; Writing – Review & Editing; Visualisation; Supervision; Funding acquisition. **AM** Data collection stage 2; Data curation; Formal analysis; Visualisation; Writing – Review & Editing. **SS** Methodology; Data collection stage 1; Data collection stage 2; Formal analysis; Writing – Review & Editing; Visualisation. **LHL** Data collection stage 1; Data collection stage 2; Formal analysis; Writing – Review & Editing. **MG** Methodology; Data collection stage 1; Data collection stage 2; Visualisation. **AV** Methodology; Data collection stage 1; Data collection stage 2; Writing – Review & Editing. **LG** Methodology; Data collection stage 1; Data collection stage 2; Writing – Review & Editing. **PDA** Data collection stage 1; Data collection stage 2; Writing – Review & Editing. **AS** Data collection stage 1; Data collection stage 2; Writing – Review & Editing. **OA** Data collection stage 1; Data collection stage 2. **PM** Data collection stage 2; Writing – Review & Editing. **WL** Data curation; Writing – Review & Editing. **BI** Data collection stage 1. **EM** Data collection stage 1. **IF** Data collection stage 2.

Competing interests

The authors declare no competing interests.

References

1. Peters, G. P. *et al.* Key indicators to track current progress and future ambition of the Paris Agreement. *Nat. Clim. Change* **7**, 118–122 (2017).
2. Berrang-Ford, L. *et al.* A systematic global stocktake of evidence on human adaptation to climate change. *Nat. Clim. Change* **11**, 989–1000 (2021).
3. Eriksen, S. *et al.* Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? *World Dev.* **141**, 105383 (2021).
4. Sparkes, E. & Werners, S. E. Monitoring, evaluation and learning requirements for climate-resilient development pathways. *Curr. Opin. Environ. Sustain.* **64**, 101329 (2023).
5. Goodwin, S., Olazabal, M., Castro, A. & Pascual, U. What makes good information to measure the contribution of urban nature-based solutions to climate adaptation? *Glob. Environ. Change* **Under review**,.

6. Fisher, S. Much ado about nothing? Why adaptation measurement matters. *Clim. Dev.* **0**, 1–7 (2023).
7. Hale, T. N. *et al.* Sub- and non-state climate action: a framework to assess progress, implementation and impact. *Clim. Policy* **21**, 406–420 (2021).
8. Arnott, J. C., Moser, S. C. & Goodrich, K. A. Evaluation that counts: A review of climate change adaptation indicators & metrics using lessons from effective evaluation and science-practice interaction. *Environ. Sci. Policy* **66**, 383–392 (2016).
9. Goonesekera, S. M. & Olazabal, M. Climate adaptation indicators and metrics: State of local policy practice. *Ecol. Indic.* **145**, 109657 (2022).
10. Klostermann, J. *et al.* Towards a framework to assess, compare and develop monitoring and evaluation of climate change adaptation in Europe. *Mitig. Adapt. Strateg. Glob. Change* **23**, 187–209 (2018).
11. Beauchamp, E. & Józefiak, I. *Next Steps for Defining a Monitoring, Evaluation, and Learning System for the Global Goal on Adaptation by COP 28*. https://www.iisd.org/publications/report/global-goal-on-adaptation-monitoring-evaluation-learning-framework-cop-28 (2023).
12. Canales, N., Klein, R. J. T., Bakhtaoui, I. & Macura, B. Assessing adaptation progress for the global stocktake. *Nat. Clim. Change* 1–2 (2023) doi:10.1038/s41558-023-01656-x.
13. Berrang-Ford, L. *et al.* Tracking global climate change adaptation among governments. *Nat. Clim. Change* **9**, 440 (2019).
14. Olazabal, M., Galarraga, I., Ford, J., Sainz de Murieta, E. & Lesnikowski, A. Are local climate adaptation policies credible? A conceptual and operational assessment framework. *Int. J. Urban Sustain. Dev.* **11**, 277–296 (2019).
15. IPCC. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge University Press (In press), 2022).
16. Reckien, D. *et al.* Quality of urban climate adaptation plans over time. *Npj Urban Sustain.* **3**, 1–14 (2023).
17. Biesbroek, R. & Lesnikowski, A. Unpacking symbolic policy-making for the first Global Stocktake under the Paris Agreement. *Npj Clim. Action* **2**, 1–3 (2023).
18. Olazabal, M., Ruiz de Gopegui, M., Tompkins, E. L., Venner, K. & Smith, R. A cross-scale worldwide analysis of coastal adaptation planning. *Environ. Res. Lett.* **14**, 124056 (2019).
19. Solecki, W. & Rosenzweig, C. Indicators and monitoring systems for urban climate resiliency. *Clim. Change* (2020) doi:10.1007/s10584-020-02947-4.
20. Tyler, S. *et al.* Indicators of urban climate resilience: A contextual approach. *Environ. Sci. Policy* **66**, 420–426 (2016).
21. Kabisch, N. *et al.* Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecol. Soc.* **21**, 39 (2016).

22. Sanchez Martinez, G., von der Pahlen, M. T., Kendrovski, V., Linares, C. & Diaz, J. Indicators to monitor policy progress in health adaptation to climate change: do they really do the job? *Eur. J. Public Health* **30**, (2020).
23. Salehi, S. *et al.* Climate change adaptation: a systematic review on domains and indicators. *Nat. Hazards* **96**, 521–550 (2019).
24. Feldmeyer, D. *et al.* Indicators for Monitoring Urban Climate Change Resilience and Adaptation. *Sustainability* **11**, 2931 (2019).
25. Chmutina, K., Lizarralde, G., von Meding, J. & Bosher, L. Standardised indicators for "resilient cities": the folly of devising a technical solution to a political problem. *Int. J. Disaster Resil. Built Environ.* **14**, 514–535 (2023).
26. Dodman, D. *et al.* Cities, Settlements and Key Infrastructure Supplementary Material. in *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Pörtner, H.-O. et al.) (2022).
27. Pearce-Higgins, J. W. *et al.* A framework for climate change adaptation indicators for the natural environment. *Ecol. Indic.* **136**, 108690 (2022).
28. Turner, S., Moloney, S., Glover, A. & Fünfgeld, H. *A Review of the Monitoring and Evaluation Literature for Climate Change Adaptation*. 55 (2014).
29. Kuhlicke, C. *et al.* Spinning in circles? A systematic review on the role of theory in social vulnerability, resilience and adaptation research. *Glob. Environ. Change* **80**, 102672 (2023).
30. Olazabal, M. & Ruiz De Gopegui, M. Adaptation planning in large cities is unlikely to be effective. *Landsc. Urban Plan.* **206**, 103974 (2021).
31. Brugnach, M. & Hoek, R. van den. Embracing ambiguity in climate change adaptation for more effective responses to new uncertain shorescapes conditions. *Mar. Policy* **152**, 105626 (2023).
32. Revi, A. *et al.* Transformative Adaptation in Cities. *One Earth* **3**, 384–387 (2020).
33. Brooks, N. & Fisher, S. *Tracking Adaptation and Measuring Development: A Step-by-Step Guide.* http://pubs.iied.org/10100IIED.html (2014).
34. Pringle, P. & Leiter, T. Pitfalls and potential of measuring climate change adaptation through adaptation metrics. in *Adaptation metrics: Perspectives on measuring, aggregating and comparing adaptation results* (eds. Christiansen, L., Martinez, G. & Naswa, P.) 29 (UNEP DTU, 2018).
35. Sainz de Murieta, E., Galarraga, I. & Olazabal, M. How well do climate adaptation policies align with risk-based approaches? An assessment framework for cities. *Cities* 103018 (2020) doi:10.1016/j.cities.2020.103018.
36. Sharifi, A. A critical review of selected tools for assessing community resilience. *Ecol. Indic.* **69**, 629–647 (2016).
37. Westman, L. *et al.* Compound urban crises. *Ambio* (2022) doi:10.1007/s13280-021-01697-6.

38. Haddaway, N. R., Macura, B., Whaley, P., & Andrew Pullin. ROSES Flow Diagram for Systematic Reviews. Version 1.0. *figshare* **Online resource.**, (2018).

Online methods

Concepts

Monitoring, Evaluation, Reporting and Learning (MERL). Also referred as M&E or MEL. With the implementation of adaptation interventions, there is a clear need to monitor, evaluate, report, and learn from actions to follow and assess progress, as well as identify good practices. The terms “monitoring”, “evaluation”, “reporting”, and “learning” collectively referred to as “MERL” make up different parts of this process. “Monitoring” refers to ongoing data collection in a systematic manner, typically through I&M whereas, “Evaluation” refers to assessments that usually occur at predefined intervals[10]. “Reporting” and “Learning” are often implied within the monitoring and evaluation process, with “reporting” referring to the processes in places for accountability and communication of results, and “learning” focusing more explicitly on measures and information used to assess “are we doing the right things” and identify areas in need of improvement[10,34].

Indicators and Metrics (I&M). Indicators and metrics are key components common to most MERL systems. However, as noted previously the terms “indicator” and “metric” are often used and expressed interchangeably as “I&M” and it is widely documented and discussed the lack of clarity between these two terms[8]. Here, an “indicator” is taken as a quality or trait that suggests a trend or “indicates” the effectiveness, progress, or success of what is being measured. In practice, this may include changes in behaviour, the orientation of buildings, the existence of a separate walking lane, or changes in living standards or awareness. Whilst, all these factors are measurable they cannot be readily quantified or tracked. By contrast, the term “metric” refers to a specific variable that can unambiguously be measured (if quantifiable) or tracked (if qualitative). Examples of metrics may include mortality rate, per capita income, built-up area, or peak flow rate.

Inputs, outputs outcomes and impacts. Adaptation I&M are either process-based or result-based. Process-based ones track the enabling environment for adaptation interventions or specific outputs resulting from the intervention itself. In this study, based on existing approaches to adaptation I&M[7,9] we categorise process-based I&M as either “input”, referring to the capacity or resources used for adaptation in the enabling environment, or “output” the direct quantitative success of project activities or products. There are broader definitions of input indicators (see Pearce-Higgins et al.[27]) that include enabling conditions or existing adaptive capacities. These have also been considered. Target indicators, as defined by Hale et al.[7] are less applicable to this scientific context. “Inputs” indicators typically measure financing, staff availability, or the number of workshops conducted, whereas “outputs” may include hectares of land restored, increase in green area, number of projects delivered, or implementation of a plan or piece of legislation. Result-based I&M track the wider effects or long-term impact of an intervention and are either outcomes, that reflect the visible short- to medium-term effects on ecological, economic, or social

systems, or “impact” that reflect the long-term impact over decades or centuries. Typically, “outcomes” measure changes such as a reduction in flooding, or increase in thermal comfort, whereas “impacts” refer to the longer-term changes such as living standards, levels of poverty, or health.

Methods

Between February 2022 and June 2023, we performed a systematic review and analysis of publications and indicators and metrics (I&M) found in scientific literature. We analysed scientific publications from the LENS scholarly literaturedatabase www.lens.orgwhich is openly accessible and diverse in the typologies of scientific publications. An original search provided 838 records, from which we selected and analysed 137 based on our inclusion and exclusion criteria (Screening and Coding Stage 1). We then collected and analysed 901 I&M (including indices) (Screening and Coding Stage 2). Eleven analysts participated in Stage 1 and 12 analysts participated in Stage 2.

The first step involved setting the scope of the review work. This scope later guided the use of the keyword search in the literature database and the identification of the publication inclusion and exclusion criteria (see Table SM1 and SM2). The whole review process is summarised in Figure SM1. We included publications related to the urban scale or having urban implications; publications related to adaptation to climate change, but not resilience, sustainability or DRR in general without a specific focus on climate change adaptation and we aimed for publications including at least one indicator or metric. We only gathered publications in the English language, to enable cross-review of collected data by the international team of analysts.

Keywords string used: Scholarly Works (838) = title:((adapt* OR resilien*) AND (indicator* OR metric* OR index OR indic* OR eval* OR assess* OR measur* OR track* OR monitor*)) AND (title:((climat*) AND (urban* OR municipal* OR city OR cities OR metropolitan*)) OR abstract:((climat*) AND (urban* OR municipal* OR city OR cities OR metropolitan*)) OR keyword:((climat*) AND (urban* OR municipal* OR city OR cities OR metropolitan*)) OR field_of_study:((climat*) AND (urban* OR municipal* OR city OR cities OR metropolitan*))) AND (title:(NOT seismic* NOT earthquake* NOT tsunami*) OR abstract:(NOT seismic* NOT earthquake* NOT tsunami*) OR keyword:(NOT seismic* NOT earthquake* NOT tsunami*) OR field_of_study:(NOT seismic* NOT earthquake* NOT tsunami*))

LENS Static Collection used for this review showed 838 records as of 15 February 2022 https://www.lens.org/lens/search/scholar/list?collectionId=199042. The LENS Dynamic Collection connected to the static collection and the same keywords string, shows 1164 records as of 29 December 2023, reflecting a 30% increase in publications in the field1164. https://link.lens.org/tGULKZKDMAj

The next step consisted of the development of a coding protocol (or documenting protocol) for both publications and indicators. Tables 1 and 2 provide a summary of the main areas documented in both instances. After data collection, there was an intense process of data curation and analyses that led to a re-categorisation of data for analysis purposes and interpretability.

Table 1. Summary of main areas that have been documented for each publication. Shaded areas show the metadata categories not included in the final dataset, as a result of incoherencies during cross-review and verification.

	Metadata category	Description
a	Disciplinary background of Lead Author (Free text)	Disciplinary background of the lead author using keywords selected by the author in Official institutional websites, Research Gate or Google Scholar.
b	*Type of study (Checkbox)*	Empirical, Conceptual/Theoretical or Review.
c	*Research Purpose (Checkbox)*	Descriptive/Exploratory, Explanatory, Evaluative
d	*Research approach (Checkbox)*	Type of methods used for analysis: Qualitative, Quantitative or Mixed methods.
e	*Case Study (Checkbox)*	Whether the research includes the validation of the assessment in a geographical study area (Yes or No)
f	*Location of case study (Checkbox)*	Region of the world where the study area for the research is located e.g. North America, Latin America, Europe, Africa, Asia, Oceania
g	*Specific location (Free text)*	Name of the city or cities and country where the study area for the research is located.
h	*Scale of study (Checkbox)*	Geographical extent of study in the region identified in (f) above e.g. Metropolitan area, Urban agglomeration, City, Peri-urban, District/ Neighbourhood
i	*Climate Hazards (Checkbox)*	Climate hazards being addressed in the publication. Adaptation to rain / river flooding, Adaptation to storm / coastal flooding, Adaptation to heatwaves, Adaptation to water security, Adaptation to food security.
j	*Adaptation measure / sector (Checkbox)*	Category of adaptation measure(s) addressed in the publication using IPCC categorisation. Land-use planning, Livelihoods and social protection, Emergency management and security, Health, Education & Comms, Cultural heritage and institutions, Temperature regulation, Air quality regulation, Stormwater and sanitation, Coastal flood protection, Riverine flood impact reduction, Water provisioning and management, Food production and security, Built form, Housing and building design, ICT (information, communication and technology), Energy infrastructures, Transport, Water and sanitation, Flood management, Coastal management.
k	*Purpose of the evaluation (Checkbox)*	Formative or Summative. Studies focusing on formative assessment involve ex-ante evaluation and continuous monitoring of the conditions from the early stages of the planning process. Studies focusing on summative assessment involve an ex-post measure of the effectiveness of interventions.
l	*Theoretical Framework (Free text)*	Theoretical framework or evaluation theory used in the publication to develop and define indicators and metrics or their frameworks.
m	*Number of indicators (Free text)*	Total number of indicators listed in the publication including composite indicator or indices
n	*Intended user or*	Target audience of the research explicitly mentioned or inferred from the text. Scientific community, Local authorities; Urban planners, Local actors in general, Financial actors,

	audience (Checkbox)	Private companies, Citizens, Regional or national government bodies, International city networks (reporting systems), Non-governmental organisation (NGO) or advocacy groups.

Table 2. Data collected for each indicator and metric identified in the literature.

	Data Collected	Description/ Examples
a	**Name**	Name of the indicator/metric as indicated in the document
b	**Composite nature**	Whether the variable is an index i.e. a composite indicator. Yes or No.
c	**Level of detail**	Tangibility in two levels: Indicator/ Metric
d	**Type**	The type of I&M identified in (c). Input, Output, Outcome or Impact
e	**Name of Adaptation Measure (if applicable)**	Name of the specific adaptation action/measures/policy connected to the indicator
f	**Dimension**	Domains evaluated or monitored by the indicator. Social/ human/ society, Economic/finance, Environmental/natural, Built infrastructure, Governance/institutional/political.
g	**Spatial scale of the indicator**	The scale to which data for this indicator is collected. City level, District level, Neighbourhood level
h	**Data Source**	Source of the data. Survey, Interviews, Spatial modelling, Statistical office database
i	**Unit of measurement**	Unit of measurement assigned to the indicator or metric.
j	**Frequency of measurement**	Frequency of measurements to be carried out to monitor the indicator or metric.
k	**Applicability of Indicator**	The applicability or use of the adaptation data that will be collected through the indicator. Assess adaptation needs and their dynamics/evolution (including changing vulnerabilities or risks, Assess efficiency of adaptation efforts and processes, Provide accountability of adaptation actions (direct outputs), Assess results (outcomes and impacts) of adaptation actions, Understand equity of adaptation progress and justice of adaptation, Improve future adaptation activities or interventions, Compare with other similar adaptation activities or interventions, Attract funding and distribute resources, Gather political momentum, Increase understanding of adaptation and its relationship with urban development, sustainability and other societal challenges.
l	**User**	Intended user of the adaptation data collected through the indicator or metric. Scientific community, Local authorities; Urban planners, Local actors in general, Financial actors, Private companies, Citizens, Regional or national government bodies, International city networks (reporting systems), Non-Governmental Organisation (NGO) or advocacy groups.

Figures

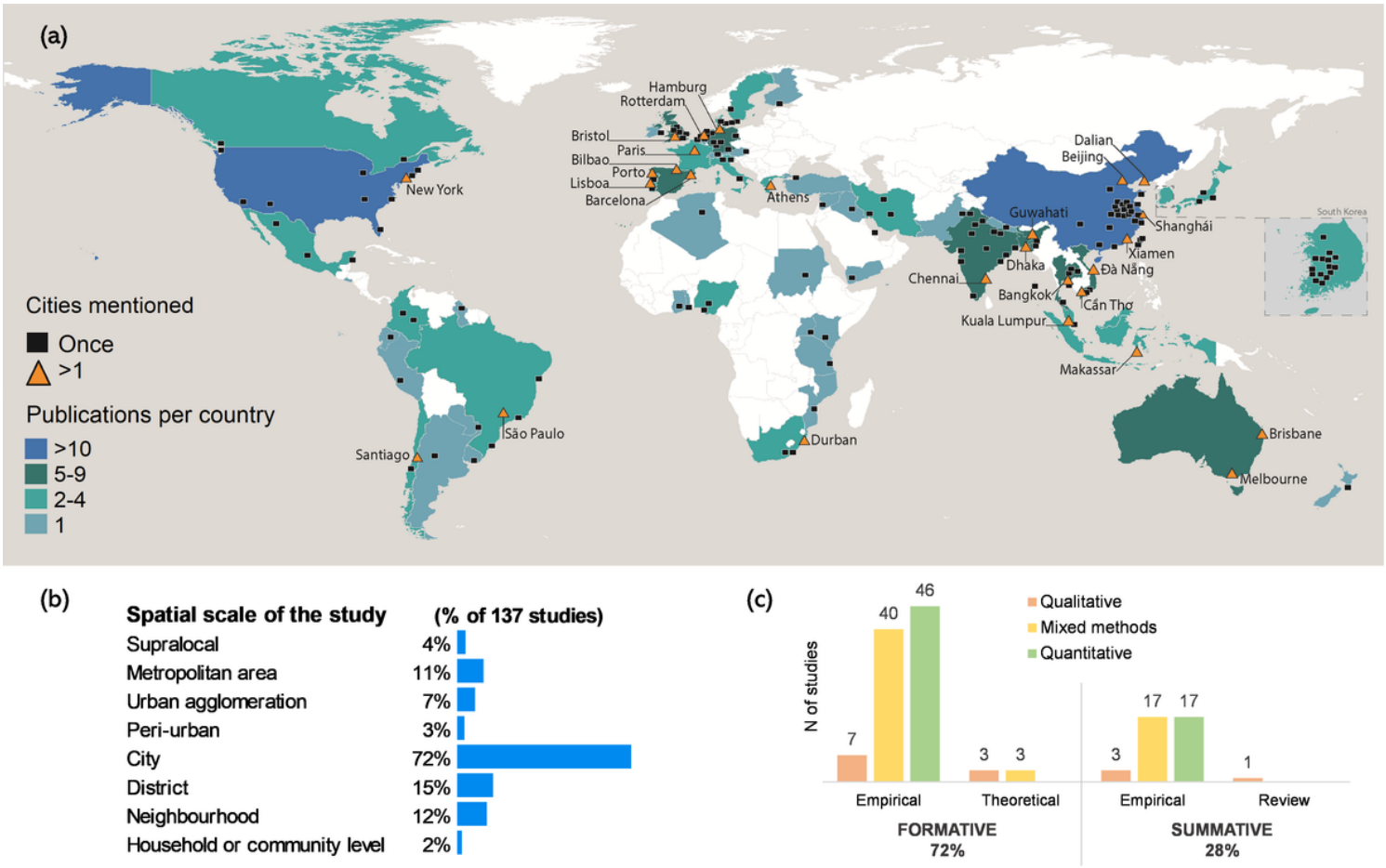

Figure 1

Analysis of 137 publications. (a) Map showing the cities and countries that have been used as application sites for adaptation indicators and metrics. The map shows the cities mentioned in the different publications and the number of publications connected to countries (as validation sites). (b) Spatial scale of the studies as a percentage of the total number of publications reviewed. (c) Type of assessments and types of methods (formative and summative, theoretical, empirical and review, and quantitative, qualitative and mixed methods).

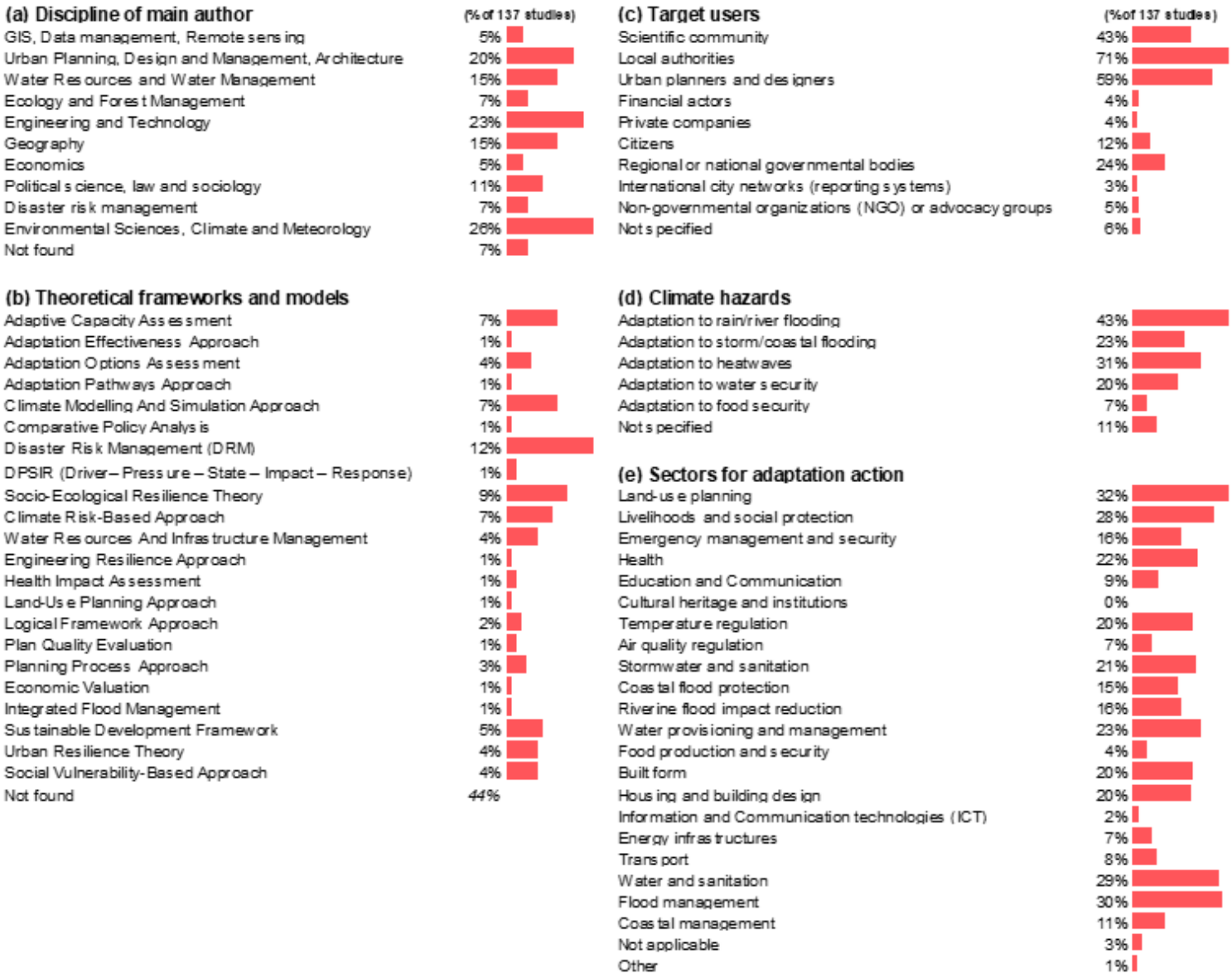

Figure 2

Analysis of 137 publications. (a) Discipline of main author (frequency) collected from institutional profiles and social media accounts; (b) Theoretical frameworks and models (frequency) inferred from publication records; (c) Target users inferred from publication records; (d) Climate hazards (frequency) explicitly mentioned in the publications records, and (e) Types of adaptation measures (frequencies) inferred in publications records. Categories for climate hazards and types of adaptation measures in urban areas correspond to those used in the 6th Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) [15,26].

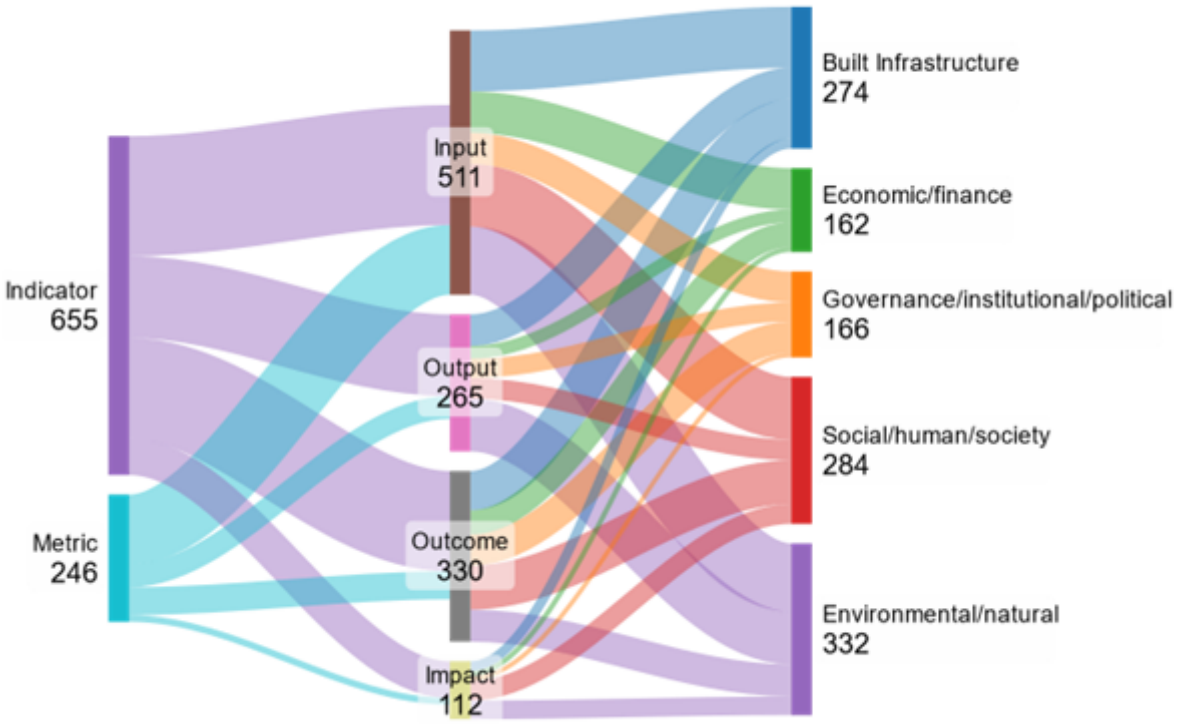

Figure 3

Analysis of 901 urban adaptation I&M. Connections between (from left to right) level of detail of Indicators and Metrics (I&M), types of I&M and dimensions visualised through a Sankey diagram. Level of detail of I&M: values show the number of indicators and metrics over a total number of 901. Types of I&M: values show the number of input, output, outcome and impact I&M over 901 total I&M. Dimension: values show the frequency for each dimension across the total 901 I&M, as I&M can be multidimensional.

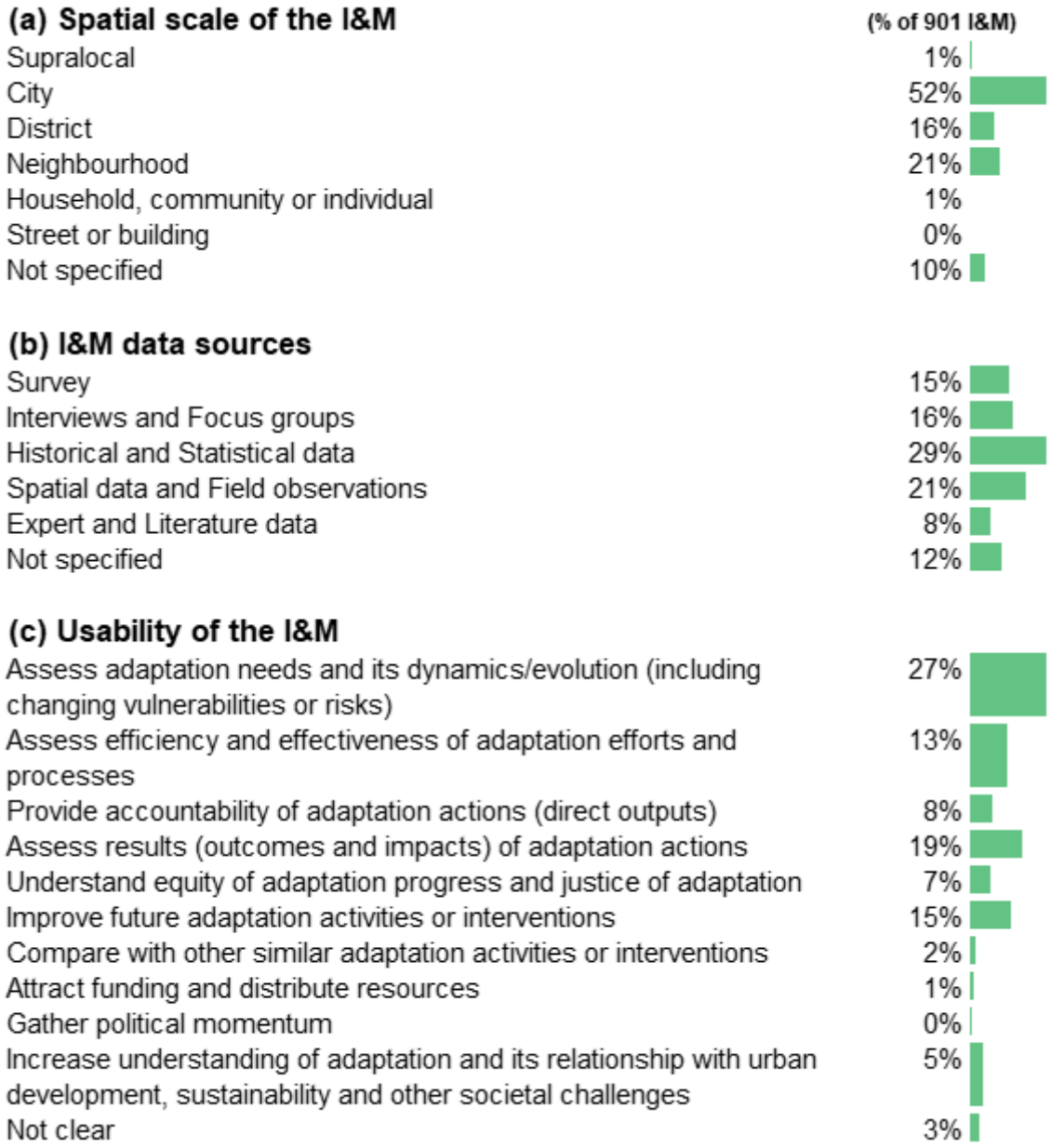

Figure 4

Analysis of 901 I&M. (a) Spatial scale (frequency); (b) Data sources (frequency); (c) Usability of each I&M (frequency) inferred from the publication records (based on Turner et al.[28]).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.docx