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Opportunities for citizen science within the Global Urban Monitoring Framework

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The Global Urban Monitoring Framework (UMF) is one of several international frameworks for monitoring progress in urban sustainable development with indicators from the Sustainable Development Goals (SDGs) and other frameworks such as the City Prosperity Index (CPI). Like the SDGs, many of the 77 UMF indicators lack data, and reporting is largely conducted at a national rather than a local level. Citizen science represents one important data source to address these data gaps at a more local level. Hence, the aim of this paper is to undertake a systematic review of where citizen science could potentially provide data for the UMF indicators using secondary data from citizen science projects. The results showed that citizen science data are already contributing and could contribute to 52 UMF indicators (~68%). Integrating citizen science into urban decision-making is essential so that local communities are at the heart of creating safe, inclusive, resilient, and sustainable cities.

This paper addresses how data gaps in urban sustainability frameworks can be filled with data from citizen science. Although urban areas only cover 3% of the Earth's terrestrial surface, they accommodate 55% of the world's population and contribute more than 70% to global greenhouse gas emissions[1,2]. With the urban population projected to reach 68% by 2050, particularly in the Global South[1], and with a high probability of exceeding the 1.5 °C target by 2030[3], there is an urgent need for sustainable urban planning and low-carbon transition pathways that ensure an adequate quality of life, which is inclusive, affordable and just. The importance of urban sustainability is acknowledged by the United Nations (UN) Sustainable Development Goals (SDGs), with an SDG dedicated to *Sustainable Cities and Communities* (SDG 11) and targets that strive for more inclusive, safe, resilient and sustainable human settlements[4]. In addition, the broader SDG framework contains several targets within the other 16 SDGs that are directly relevant to both urban and rural human settlements; an example is Target 6.1, which is the achievement of equal access to safe and affordable drinking water affecting both urban and rural areas.

In addition to the SDGs, there are several relevant frameworks that highlight the importance of urban and rural contexts in advancing sustainability, such as the Sendai Framework[5], the Addis Ababa Action Agenda[6], the Global Biodiversity Framework[7], and the Paris Agreement[8]. For example, the Sendai Framework's Global Targets E and G, which aim to substantially increase the number of countries with national and local disaster risk reduction strategies, and availability of and access to early warning systems and disaster risk information, have specific indicators that highlight the critical role of local contexts and governments in achieving its goals; G-4: Percentage of local governments having a plan to act on early warnings is one example illustrating this.

Additionally, there are also frameworks that specifically address urban areas, such as the New Urban Agenda (NUA)[9] alongside numerous national urban policies and regional development plans. However, to provide a more integrated approach to monitoring urban areas that include elements of the SDGs, the NUA and other city-localized measurement approaches, such as the City Prosperity Index (CPI)[10] in a single place, UN-Habitat led the process of developing the Global Urban Monitoring Framework (UMF)[11]. The UMF serves as a monitoring tool for the UN-Habitat's Flagship Programme SDG Cities. Endorsed by the UN Statistical Commission in March 2022, the UMF is also a useful tool for Voluntary Local Reviews (VLRs) and for preparing data for Common Country Assessments. VLRs are local level evaluations conducted by cities, regions or other subnational authorities to assess progress toward achieving the SDGs. While modeled on Voluntary National Reviews (VNRs)[12] and not officially mandated, VLRs have become vital tools for localizing the 2030 Agenda, fostering policy coherence and promoting transparency and accountability[13]. In this context, the UMF provides a standardized set of indicators and metrics that cities can use in their VLR processes, helping to ensure consistency in data collection and alignment with national and global monitoring systems, including the local aspects of the SDGs. More broadly, the SDG and UMF monitoring architecture operates as a multi-level system that leverages data, indicators and reporting mechanisms to track sustainable development progress[14]. This

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structure ensures that local actions feed into national and global assessments, while also empowering cities to shape and evaluate their own sustainable development pathways.

The UMF consists of five domains with a total of 77 indicators: society, economy, culture, environment and governance & implementation and four objectives, which are to achieve safe and peaceful, resilient, inclusive and sustainable cities. The framework is the result of a collaboration between various UN agencies, regional commissions, city representatives and more than 25 partners from institutions working with urban indicators[11]. The status of the availability of data on the UMF indicators for 466 cities has been published by UN-Habitat[15].

As with the SDGs and many other monitoring frameworks that use indicators as a way of tracking progress in achieving their goals or targets, much of the data needed to calculate these indicators is still lacking. For example, the UN assessment of SDG progress in 2024 showed that trend data (at least two data points in time since 2015) are still missing for 49% of the indicators in half of the world's countries[16]. Moreover, there is an imbalance in data availability across the SDGs, with SDG 5 (gender equality), SDG 13 (climate action) and SDG 16 (peace, justice and strong institutions) having greater shortfalls in data compared to other SDGs. Finally, the timeliness of the data is problematic, with one third of countries lacking data for the past three years. Hence there is a need for alternative data sources to help monitor the SDGs and other urban indicators.

Data generated by the public have already been identified as a non-traditional source of data that can be used to fill some of these data gaps[17,18], including by the UN[16]. Such data, also known as citizen-generated data, citizen data, citizen science, crowdsourcing, community-based monitoring, volunteered geographic information and others[19], refer to the production of knowledge by individuals and communities, which can be used for scientific research and to provide evidence for change. While each of these terms carry specific nuances in certain contexts and are used interchangeably across the literature, for the purposes of this paper, and as outlined in the methods section in more detail, here, we use citizen science as an umbrella term to encompass the diverse terminologies, definitions and approaches that involve public engagement. We define citizen science broadly as the participation of members of the public in the process of knowledge production, through the contribution of their skills, expertise, and local knowledge to address research questions or issues of concern to themselves or their communities[20]. The Ten Principles of Citizen Science provide guidance on good practices in citizen science, including principles such as making data and metadata publicly available, publishing results in open-access formats where possible, and addressing legal and ethical considerations, such as copyright, confidentiality, attribution and the environmental impact of activities[21,22].

In addition to addressing data gaps, there are several advantages of involving the public in urban monitoring and the monitoring of sustainable development more broadly. For example, many citizen science projects are local in nature, aligning well with the scale of urban monitoring. They can also address a very wide range of environmental and social issues, e.g., from biodiversity[23] and air pollution monitoring[24] to urban climate justice in slum areas[25] and youth-led infrastructure monitoring such as mapping of broken water pumps (https://donatewater.ng/). At the same time, they can provide an approach that can help to gain a better understanding of issues that are relevant to people whilst promoting community building and resilience[26]. Monitoring can be undertaken with technical sensing devices, but the approach can also be much more subjective, e.g., gathering perception data on the quality of urban greenspaces[27]. Finally, inclusivity is a key ingredient of sustainable development and the core SDG principle of leaving no one behind, which cannot be achieved without ensuring equal opportunities for everyone and enabling the participation of all, including the most vulnerable and marginalized. Although challenging, this is an area of great attention in the research and practice of citizen science[28].

Some studies have already been undertaken in the past to investigate the potential of citizen science for monitoring progress in relation to the SDGs. For example, all SDG indicators were systematically reviewed by Fraisl et al.[29] to determine whether citizen science could contribute data to their calculation or could indirectly provide context for monitoring. The review found that citizen science is already contributing to five SDGs but has the potential to contribute to around one-third of all SDG indicators. Using the same methodology, a similar review was undertaken by Fraisl et al.[30], focusing this time on health-related SDG indicators in collaboration with the WHO, particularly as SDG 3 *Health and Well-being* was identified as having considerable potential for inputs from citizens[29]. They found that citizen science could potentially contribute to 83% of these health-related indicators.

Taking a broader view of contributions at the target and goal level and focusing on the 44 projects funded by the European Commission that included citizen science[31], it was found that more than 100 cities across Europe were involved in these projects, which primarily addressed SDG 3 *Health and Well-being*, SDG 11 *Sustainable Cities and Communities* and SDG 13 *Climate Action*. However, greater alignment is needed between the national and city level if citizen science contributions to the SDGs are to be fully realized. Other reviews of citizen science contributions to the SDGs also found that potential contributions were highest in SDGs 3, 4, 7, 11, 14, 15 and 17[32–36], but some identified relevance to other SDGs[37]. The study by Pateman et al.[33], in particular, undertook a review of the contribution of citizen science projects in cities located in low- and middle-income countries. They found that projects aligned with 35% of SDG targets, but that there was less alignment with the SDG indicators, where projects could contribute to the monitoring of only 8 urban-related indicators. However, regarding the implementation of the SDGs, they found 46 indicators to which projects could contribute. Moreover, they found only a small number of projects in low-income countries, demonstrating the limited potential of citizen science to make contributions, particularly in Africa.

Despite the increasing number of studies that have been investigating the potential contributions of citizen science to the SDGs, there have not yet been any attempts to systematically review citizen science contributions to the UMF, which is the aim of this paper. The UMF was specifically chosen as it covers urban-relevant SDG indicators, along with those from other aforementioned frameworks, providing a more comprehensive approach to monitoring various aspects of urban sustainability across these frameworks. Here we follow a similar methodology to that undertaken by Fraisl et al.[29,30] by systematically determining how citizen science can contribute to the UMF as a way of addressing data gaps, but also to provide contextual information related to better understanding and monitoring urban sustainability. We also use the database provided by UN-Habitat on the current status of the data availability (accessed January 2025) based on city reviews[15] to determine whether any reported data gaps could be addressed by citizen science projects and approaches.

Results

The outcomes of the mapping of citizen science projects (including related initiatives as outlined in the methods) to the 77 indicators of the UMF are summarized in Figs. 1 and 2, organized by domain (i.e., society, economy, environment, culture, and governance & implementation) and overarching objective (i.e., of fostering safe and peaceful, inclusive, resilient and sustainable urban environments). Overall, this mapping indicates that citizen science currently contributes to 3 UMF indicators (or around 4%) but has the capacity to contribute to an additional 49 UMF indicators (i.e., 64%), demonstrating their relevance to urban monitoring needs.

Citizen science holds the greatest potential for contributing to UMF indicators within the environment domain. It currently contributes to one indicator under the resilient cities objective and has the potential to contribute to 10 more, covering 85% of indicators in this domain (Fig. 2). The society domain follows closely, with citizen science having the potential to contribute to 20 out of 24 indicators (83%). In the culture domain, citizen science could support 5 out of 9 indicators (56%), while there is also potential for contributions to the economy domain by supporting 8 of 15 indicators (53%), particularly in areas such as informal employment and access to public transport. Finally, in the governance & implementation

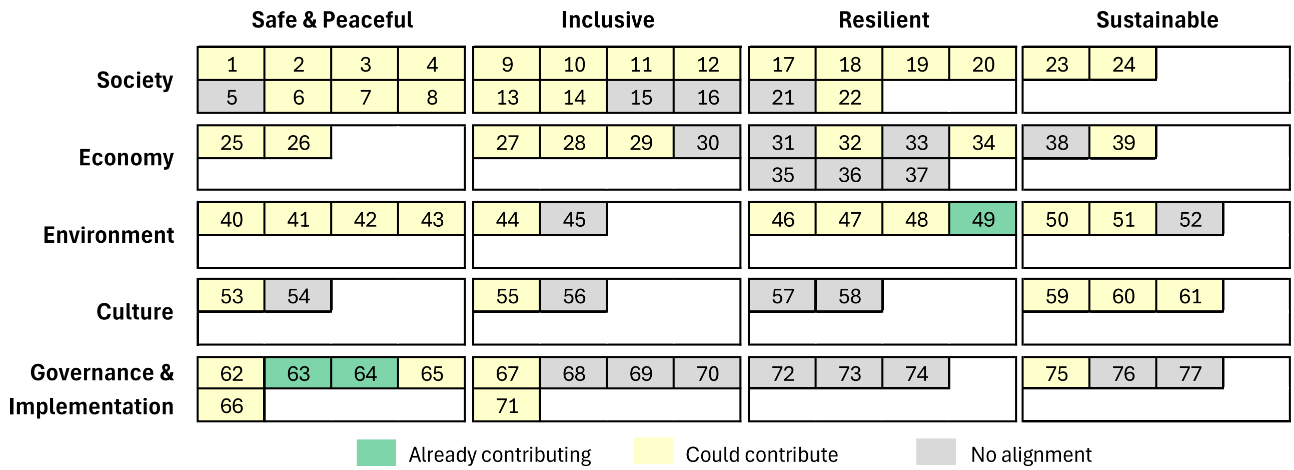

Fig. 1 | Citizen science potential across the Global Urban Monitoring Framework. The UMF indicators from 1 to 77, listed by domain and objective, shaded according to whether citizen science is already contributing (4%) to the indicator, whether it could potentially contribute (64%) or whether there is no alignment (32%) between the indicator and citizen science.

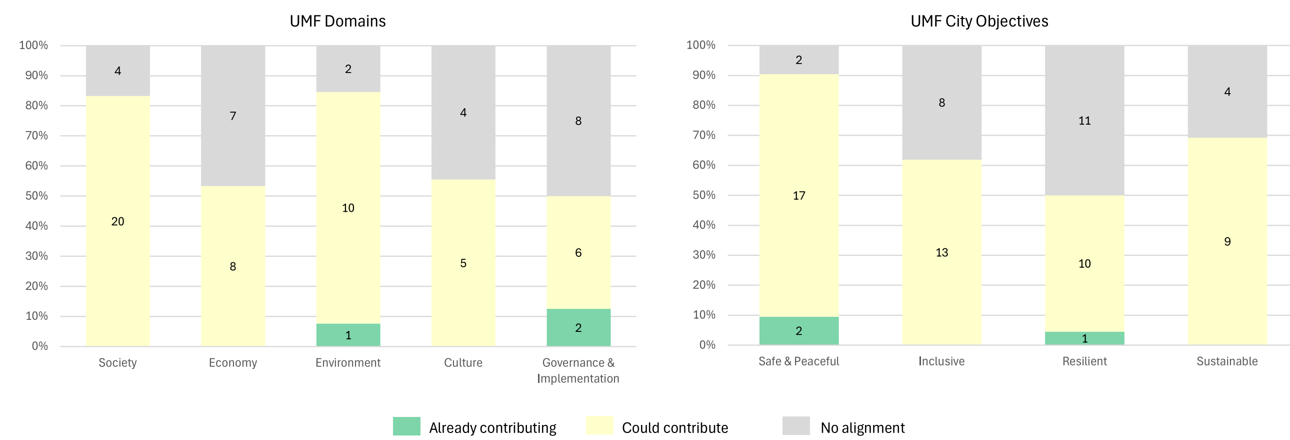

Fig. 2 | Distribution of UMF indicators by domain and objective with citizen science potential. The absolute and relative number of UMF indicators by domains and objectives shaded according to whether citizen science is already contributing to the indicator, whether it could potentially contribute or whether there is no alignment between the indicator and citizen science.

domain, there are two indicators that are already being directly supported by citizen science projects (contributing to the objective of safe and peaceful cities) and six further indicators where citizen science could potentially contribute, covering around 50% of all indicators in this domain.

Figure 2 also highlights that the greatest potential for contributions by citizen science are related to the objective of achieving safe and peaceful cities with 90% alignment while the fewest contributions of citizen science are related to achieving resilient cities at 50% alignment, even though one indicator is already supported directly by contributions from citizen science.

Citizen science contributions across UMF domains

As outlined above, the environment domain shows the greatest potential for contributions from citizen science. Among the 13 indicators, citizen science directly contributes to one indicator, UMF-49 (protected natural areas), which overlaps with SDG indicators 15.1.2 (proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type) and 15.4.1 (coverage by protected areas of important sites for mountain biodiversity). 65% of the world's Key Biodiversity Areas (KBAs) are partially or fully covered by protected areas. KBAs also include Bird and Biodiversity Areas that have been defined using various data sources including citizen science[38]. Hence, the delineation of some protected areas is also based on inputs from citizen science data. Therefore, even if citizen science data have not been directly used to report on this UMF indicator, they hold significant potential for integration into their monitoring, as these data are already utilized in SDG monitoring and reporting[17,29]. In addition, citizen science could contribute to ten other indicators; examples include UMF-42 (air quality) via projects such as Sensor.Community and PurpleAir, which empower communities to measure and share localized air quality data, and UMF-44 (access to open public spaces), which could be determined through initiatives such as OpenStreetMap, Maptionnaire and the Green Map System. Moreover, geospatial data on usage, infrastructure, and perceptions of public spaces, such as those collected in the Urban ReLeaf project[39], can provide actionable insights for urban planners and policymakers to enhance inclusivity and accessibility to open public spaces.

The society domain of the UMF reveals strong potential for citizen science contributions, with 20 of the 24 indicators showing alignment, while 4 lack compatibility with citizen science approaches. For UMF-02 (access to safe drinking water), initiatives like Donate Water utilize crowdsourced data to map water access and quality, focusing on vulnerable populations in Nigeria. Started by a group of young people, this initiative engages communities through a mobile app to track water sources, assess water

Domain	Africa	Asia	Europe	North America	Australia	Rest of Oceania	South America
Society	59.2	58.1	50.4	54.2	71.0	50.7	56.1
Economy	51.7	50.1	49.6	46.7	68.4	43.9	49.1
Environment	33.9	37.6	34.0	33.7	75.4	34.0	37.8
Culture	8.5	9.9	5.8	11.9	48.5	7.0	10.2
Governance & Implementation	24.1	24.5	21.2	22.0	54.9	20.7	25.0

Fig. 3 | Data completeness of UMF indicators across continents and domains. Completeness of UMF indicator availability for all 77 indicators by continent (aggregating results across the cities) and by UMF domain. The distribution of the 466 cities across the continents were: Africa (100), Asia (145), Europe (81), North America (66), Australia (11), Rest of Oceania (18), and South America (45).

inaccessibility and identify those most vulnerable to droughts caused by climate change. UMF-06 (neighborhood safety) could be supported by projects such as SafetiPin and MapKibera where citizens audit public spaces for safety features like lighting and infrastructure, providing actionable data to improve urban planning. Mapping platforms also play a key role in UMF-09 (access to basic services). OpenStreetMap (OSM) and the Resilience Academy engage citizens to map critical urban infrastructure, such as healthcare facilities, schools, and water sources, offering localized data to improve service access and equity. However, four indicators in the society domain show no alignment with citizen science: UMF-05 (proportion of births in health facilities), UMF-15 (welfare of migrants), UMF-16 (multilingual education) and UMF-21 (mortgage debt relative to GDP), which rely on institutional data, making them less suitable for citizen science-driven methods.

Within the economy domain, there are eight indicators that could be supported by citizen science. Indicative examples include UMF 27 (unemployment rate) that could be informed by projects such as the Youth Voice Census in the UK, where young people provide important disaggregated data to identify barriers to job access and inform labor policies, and UMF-29 (use of public transport), which could be supported by projects such as Moovit and BusMap Lebanon that engage communities in mapping public transport and paratransit systems, including the routes and stops. These initiatives also offer critical insights into transport accessibility and usage patterns that are valuable for urban mobility planning and development. However, certain indicators in the economy domain, such as UMF-31 (annual growth rate of GDP per capita), UMF-37 (patent applications) and UMF-38 (sub-national debt), have no alignment with citizen science. These indicators depend on macroeconomic data from finance ministries and banks, patent registries, and sub-national fiscal records, which are beyond the scope of citizen science.

A review of the culture domain indicates that citizen science could contribute to five of the nine UMF indicators. Notably, OpenHistoricalMaps and OSM are established community mapping tools that could contribute to the monitoring of UMF-59 (sustainable management of heritage) and UMF-61 (open space for culture), respectively, across urban environments. Other indicators, such as UMF-57 (cultural employment) and UMF-58 (expenditure on heritage), are dependent on institution-specific data and have no current alignment with citizen science.

Finally, the governance & implementation domain of the UMF includes 16 indicators, with citizen science directly contributing to UMF-63 (victims of physical and sexual violence) and UMF-64 (intimate partner violence). The Ghana Statistical Service (GSS) has used citizen science approaches to gather information on several connected SDG indicators (5.2.1, 5.2.2, 11.7.2 and 16.2.3). The project involved pilot work in three districts representing all three ecological zones of Ghana (Ho, Techiman, and Central Gonja), with plans for a nationwide rollout. Through a design-thinking approach, an app and an Interactive Voice Response service called Let's Talk were created, allowing participants to anonymously report information about gender-based violence. When comparing the results to traditional data collection methods, the GSS found that citizen science approaches helped to gather more data, as many women may otherwise not have reported violence through official channels[30]. Although the data may not have been directly used to report on the aforementioned UMF indicators, it has significant potential for integration into the monitoring of both the UMF and the SDGs, given that it is an initiative led by a National Statistical Office (NSO), the government agency that is responsible for collecting, compiling and releasing official statistics in a nation. For the same reason, it could also play a crucial role in informing policymaking in the country. As a result, it has been mapped as a direct contribution in our review. Similarly, projects like the iWitnessed app enable anonymous, real-time reporting and analysis of violence incidents, generating valuable data for public awareness campaigns, workplace training, and policy development. Digital platforms such as Participedia and Smarticipate are also popular mechanisms for citizens to co-create urban solutions, fostering public participation in city planning (UMF-67). Despite the potential, the governance & implementation domain revealed 8 indicators that are not currently aligned with citizen science initiatives. For example, the consistent monitoring of UMF-72 (own source revenue collection) and UMF-73 (financial autonomy) require sensitive financial data related to intergovernmental agreements and frameworks, where there is limited scope for citizen science data to make meaningful contributions.

The completeness of UMF indicator reporting

Using the "Urban Monitoring Indicators Combined Dataset" compiled by UN-Habitat (dated September 2024), which indicates the status of UMF data availability in 466 cities[15], the data completeness was analyzed by domain and continent, shown in Fig. 3. The society domain demonstrates the highest completeness globally, with cities in Africa, Asia, and Australia consistently having the most indicator availability, resulting in a global average of 56.3% completeness. This is followed by indicators in the economy domain, with an average global completeness of 50% and relatively consistent reporting across most continents. Indicators in the environment domain exhibit a global average of 36.4% completeness. However, Australia stands out with notably high completeness in this domain (75.4%) compared to all the other continents that show less than 40% completeness overall. The culture domain has the lowest completeness levels across all continents, with a global average of just 10.0% and cities in Europe reporting 5.8% of indicators in this domain. Finally, indicators in the governance & implementation domain have a global average completeness of 24.1%, with cities in Australia leading the reporting (54.9%), while cities in other continents exhibit lower levels of data availability. Overall, across all domains, cities in Australia demonstrate the highest data completeness, outperforming cities from other continents.

The scale of UMF indicator reporting

The Urban Monitoring Indicators Combined Dataset also contains information on the scale at which each indicator is reported, i.e., at national, sub-national or city level. Figure 4 shows that less than 20% of all indicators are, on average, reported at the city level, with the highest percentage (20%) occurring for cities in Africa. Overall, the majority of indicators are reported at national level despite being urban indicators. In such cases, national and sub-national values are used as proxies for city-level values. However, in Australia, around 54% of indicators are reported at the sub-national level.

Citizen science and the current data gaps in the UMF database

For each domain, the five UMF indicators with the highest percentage of missing data are shown in Fig. 5, differentiated by whether citizen science is

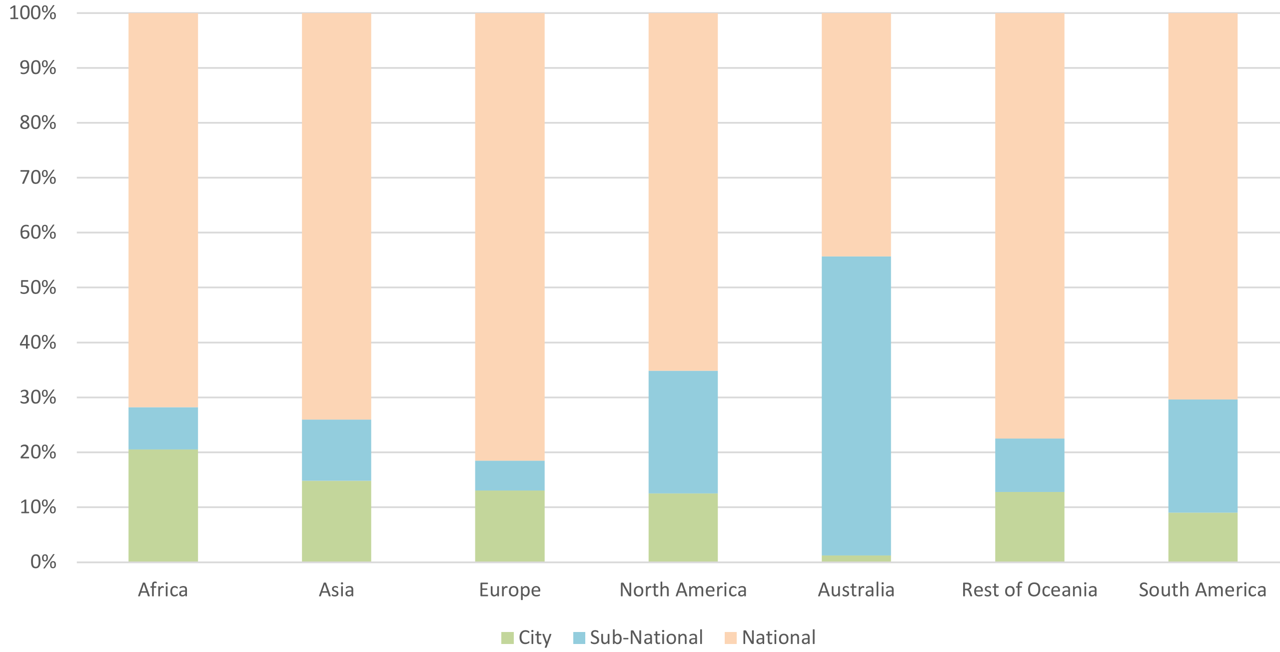

Fig. 4 | Scale of UMF indicator reporting across continents. The percentage of UMF indicators reported at the national, sub-national and city scales by continent. Note that Oceania is separated into Australia and the Rest of Oceania to highlight the difference in patterns across these two regions.

Domain	Indicator	Description	Data completeness	National	Sub-National	City
Society	UMF9	Basic services	4.7	17.5	79.4	9.5
	UMF10	Access to public transport	29.6	10.3	37.5	52.2
	UMF12	Secure tenure rights to land	35.3	99.3	0.0	0.7
	UMF15	Welfare of migrants	0.0	0.0	0.0	0.0
	UMF16	Multilingual education	0.4	100.0	0.0	0.0
Economy	UMF25	Children engaged in child labor	26.1	81.8	15.3	2.9
	UMF26	Time spent on unpaid domestic and care work	24.0	93.6	5.9	0.5
	UMF29	Use of public transport	18.5	15.3	57.6	27.1
	UMF32	Youth and adults in formal and non-formal education and training	26.9	99.5	0.0	0.5
	UMF38	Sub-national debt	27.9	80.6	17.6	1.9
Environment	UMF41	Solid waste collection and disposal	18.6	47.0	15.2	37.7
	UMF44	Access to open public spaces	18.2	2.4	31.3	66.3
	UMF47	Green area per capita	21.2	20.4	40.8	38.8
	UMF51	Efficient land use	12.4	0.0	60.7	39.3
	UMF52	Budget on climate change mitigation and adaption	5.6	0.0	100.0	0.0
Culture	UMF54	Cultural knowledge	0.0	0.0	0.0	0.0
	UMF55	Access to culture	0.0	0.0	0.0	0.0
	UMF56	Cultural participation	4.6	62.5	34.4	3.1
	UMF59	Sustainable management of heritage	0.0	0.0	0.0	0.0
	UMF61	Open space for culture	0.0	0.0	0.0	0.0
Governance & Implementation	UMF63	Victims of physical and sexual violence	6.9	38.8	5.1	56.1
	UMF65	Reporting of violence	10.3	70.8	25.0	4.2
	UMF67	Participation in urban planning and management	0.6	33.3	0.0	66.7
	UMF71	Efficiency in urban governance	0.0	0.0	0.0	0.0
	UMF77	Governance of culture	0.0	0.0	0.0	0.0

Already contributing Could contribute No alignment

Fig. 5 | Least complete UMF indicators by domain and their citizen science potential. For each domain in the UMF, the five indicators with the lowest level of completeness across all cities are shown in ranked order, shaded according to whether citizen science is already contributing to the indicator (green), whether it could potentially contribute (yellow) or whether there is no alignment between the indicator and citizen science (gray). To the right of each indicator is the scale at which the indicator is reported, i.e., the distribution by national, subnational and city levels.

contributing, could contribute or having no alignment. From these 25 indicators, citizen science is already contributing to one of them while it could potentially contribute data to 17 of these indicators. Some of the indicators in Fig. 5 are reported largely at national level, e.g., UMF-12 (secure tenure rights to land), as well as some of the indicators in the economic domain, which could also benefit from a more local citizen science and community-based approach. Others have much higher reporting at the city level, e.g., UMF-44 (access to open public spaces), which could benefit from already established citizen science projects. The full list of indicators is provided in Figs. S1–S5 (each corresponding to a single domain) of the Supplementary Information.

Discussion

This study represents the first comprehensive review of citizen science contributions to the UMF. While previous research, including our own, has explored the role of citizen science in monitoring the global SDG indicator framework[29,37], health and well-being related SDGs and the WHO's Triple Billion Targets[30], and the Kunming–Montreal Global Biodiversity

Framework (GBF)[40], among others, none have specifically focused on the UMF or the broader monitoring of urban sustainability. Additionally, by examining the data in the UMF indicator database for 466 cities, this study is the first to systematically align the identified data gaps in this database with citizen science contributions. This alignment provides a practical repository of citizen science initiatives and actionable insights for cities, enabling them to meet their specific urban monitoring and reporting needs.

Our findings show substantial potential for citizen science to support UMF monitoring. Compared to the contribution potential of 33% for the SDGs[29], 83% for the health and well-being-related SDGs and the WHO's Triple Billion Targets[30], and 51% for the GBF[40], citizen science can potentially contribute to 68% of UMF indicators. This high potential likely reflects the urban focus of the UMF, which aligns well with the predominantly local and community-centered nature of many citizen science initiatives, as opposed to larger-scale efforts, such as regional or global projects. Moreover, unlike large-scale regional or global monitoring efforts, citizen science projects often engage directly with local urban challenges, making them well-suited for supporting UMF indicators.

Our findings are consistent with earlier studies showing that citizen science data contribute most substantially to the environment domain[29,40,41]. Key areas of contribution in this domain include biodiversity monitoring, air quality, and land and tree cover detection, among others. The society domain closely follows the environmental domain, with indicators covering issues such as child mortality, access to basic services, adolescent birth rates, and malnutrition in children. These findings are in alignment with a previous study[30], which reported the potential for an 83% contribution from citizen science to health and well-being indicators. Notably, the UMF includes a unique domain that is not covered extensively in the aforementioned indicator frameworks, which is culture. This domain addresses topics such as cultural knowledge, access to culture, cultural participation, and expenditure on cultural heritage, with citizen science potentially contributing to approximately 56% of these indicators. More generically, our findings show that, across all domains, indicators that rely on (i) perceptions (such as feeling safe walking alone), (ii) the use of geospatial data (such as access to basic services or cultural infrastructure), (iii) community surveys to complement traditional data sources (such as open space for culture), and (iv) participatory design, urban development, and management (such as direct participation of civil society in urban planning and management) are more suited to citizen science approaches. Our results also show that the lowest contributions from citizen science are in the governance & implementation domain. This may be due to the nature of the indicators in this domain, which often involve finance- and policy-related topics requiring data from authoritative sources. For instance, indicators like 5.4.2 (presence of urban policies or regional development plans that: (a) respond to population dynamics, (b) ensure balanced territorial development, and (c) increase local fiscal space) are less amenable to citizen science methodologies.

Although our findings show that citizen science has the potential to contribute to 64% of UMF indicators, it is currently only contributing to 4%, underscoring a significant gap between potential and practice. The transition from "could contribute" to "already contributing" in citizen science faces significant methodological and structural challenges. One key issue is the misalignment between the design of most citizen science projects and the standardized data and quality requirements of official frameworks such as the UMF. These frameworks demand consistent methodologies and formal validation processes, which are criteria that many citizen science initiatives are not originally designed to meet. Alignment with such standards requires substantial investment in training and technical support. However, these projects often lack financial resources and long-term planning needed to comply with official requirements. Another key barrier is the skepticism that persists among public authorities and policy communities regarding the accuracy, credibility and relevance of citizen science data[42]. Political will is often absent, particularly where traditional methods and data infrastructures are already in place. Additionally, many city officials and official statistical agencies remain unaware of the potential value that citizen science data can provide, hindering its integration into official monitoring and reporting systems[43]. Overcoming these challenges requires capacity building on both sides, within citizen science communities to understand and align with the official standards to the extent possible, and within city administrations and statistical institutions to better understand and embrace citizen science as a valuable data source and participatory approach. Ultimately, mutual understanding, collaboration, and institutional support are essential for citizen science to meaningfully contribute to official and city-level data ecosystems.

In terms of data completeness, our analysis of the currently available data on the Urban Monitoring Indicators Combined Dataset reveals large regional variations (Fig. 4). Notably, cities in Australia demonstrate higher data completeness across all UMF domains, while other continents, particularly Europe, show notable reporting gaps. While various factors may contribute to this discrepancy, further investigation is needed to understand the underlying causes. However, one possible reason could be the varying regional priorities related to urban policies, as well as differing levels of awareness and adoption of the UMF framework in addressing urban sustainability challenges. Additionally, disparities in data completeness may be influenced by broader administrative, political, and institutional contexts. For instance, more centralized governance structures might support more coordinated and consistent reporting, whereas in more decentralized systems, data collection and submission can be more fragmented. More specifically, in the case of Australia, the relatively high data completeness may also reflect the benefit of operating within a single national context, in contrast to Europe and other regions depicted in Figs. 3 and 4, which comprise multiple countries with diverse governance arrangements and reporting practices. These contextual differences likely influence both the consistency and availability of reported data. To address these disparities in general, UN-Habitat and partners could consider developing region-specific strategies to enhance UMF reporting, tailored to the unique contexts and priorities of each region. Additionally, our findings suggest that, since most indicators are reported at the national level and, on average, less than 20% are reported at the city level, citizen science data could serve as a solution to data incompleteness, bridging critical gaps in UMF reporting. By leveraging the localized and community-driven nature of citizen science, this approach could enhance the accuracy and granularity of urban sustainability reporting, making it more relevant for city-level decision-making.

Our study has several limitations. For example, due to the broad scope of citizen science as a concept, we acknowledge that not all relevant projects may have been included in our review. Additionally, not all initiatives have an online presence, which means we may have overlooked some projects with great potential or those that are already contributing to UMF monitoring and reporting. Our use of ChatGPT for project identification was experimental and did require manual verification, but in the future, we could explore the use of this tool in the validation process (step 4), which was also undertaken manually. Language was another limitation, as we focused exclusively on initiatives with an English-language online presence. Therefore, we must note the bias towards initiatives that publish in English, which could limit the diversity of the projects identified. Another issue was that even for those with an English online presence, the information available was not always up to date. However, despite these limitations, our primary goal was to identify initiatives with potential, without needing to be exhaustive. Therefore, our analysis could serve as a foundation for more focused research covering different languages, domains or indicators.

Additionally, we did not analyze the data sets and methodologies of all the projects identified in detail as this information may not be readily available online. This limitation highlights a broader challenge as limited access to data can hinder the integration of citizen science data into official urban monitoring frameworks. Although evaluating data quality and availability was not the primary aim of this review, our broader experience during the study is consistent with findings in the literature, which highlight that many citizen science initiatives do not consistently share their data[44,45]. This is often due to resource limitations, insufficient data management capacity, privacy concerns, the need to respect community ownership and protect sensitive information[46]. However, ensuring open access to data outputs, along with documentation of protocols, definitions and metadata standards is essential for enabling the reuse of citizen science data in official monitoring and policy development efforts. It is necessary to consider the trade-offs between data availability, quantity, and quality. Even when data are accessible, uptake into official frameworks may be limited if concerns about reliability persist, particularly for perception-based or fragmented data. However, this very nature of citizen science makes it well suited for UMF indicators that rely on subjective inputs, such as how one feels when walking alone. For other indicators, citizen science data can be valuable when trade-offs are managed through robust project design, quality assurance and alignment with indicator and policy requirements.

Another significant barrier to the integration of citizen science data within UMF monitoring is ensuring consistency and comparability of data across diverse urban contexts. Variations in data collection protocols, participant demographics, and degrees of representativeness can affect data quality and limit the consistency required for integration into official frameworks. Addressing these challenges requires implementing standardized data collection protocols, adopting common metadata frameworks, and aligning with the definitions and methodologies set by the UMF and other international monitoring frameworks[41]. Calibration strategies such as validation against reference datasets and parallel data collection by professionals could improve the reliability and comparability of citizen science data. Furthermore, comprehensive metadata documentation along with quality assurance processes is essential for identifying limitations and enabling corrective measures. These practices support methodological harmonization, facilitate data sharing, and improve the usability of citizen science data in official monitoring.

Future research could explore the quality of the data (i.e., the accuracy, representativeness, interoperability) in the context of official statistics and policymaking, potentially through in-depth interviews or other methods, to better understand the data quality and usability, which are key concerns of NSOs[47]. Additionally, further work could investigate strategies for building trust among citizen science initiatives, local governments, the official statistics community, and decision-makers. Strengthening these relationships is essential for enhancing the credibility, acceptance, and long-term integration of citizen science in urban monitoring and policy development. Future research could also focus on practical demonstration cases where citizen science has been applied to areas with strong potential for contributing to UMF monitoring such as in the environmental domain. Such case studies could help assess feasibility across different contexts, topics, and indicators and generate valuable insights and lessons to inform the broader scaling up of citizen science approaches in urban sustainability monitoring.

It is important to acknowledge the growing interest in citizen science from NSOs and the official statistics community. For example, the integration of citizen science data into official SDG reporting for indicator 14.1.1b (plastic debris density) in Ghana shows considerable promise[48]. However, such use cases remain limited. To leverage the full potential of citizen science in monitoring the UMF and overcoming data gaps, stronger institutional collaboration is required.

Initiatives such as the UNSD's Collaborative on Citizen Data[49] and the Citizen Science Global Partnership (CSGP)[50] offer pathways to bridge the gap between community-driven data and institutional reporting requirements[50,51]. Embedding citizen science into the early design stages of monitoring frameworks can improve data credibility, policy relevance, and long-term sustainability. Such design considerations could help trigger inclusive and participatory governance models that not only address persistent data gaps but also tackle local realties and community needs. At the same time, members of the citizen science community aiming to have their data influence global frameworks and related policies should actively align their data collection, validation, and reporting methods with those used in established frameworks such as the UMF. This alignment is critical for transforming citizen science from a supplementary data source to a mainstream component of urban sustainability monitoring.

It is also important to note that the potential of citizen science to extend beyond addressing data gaps in global frameworks such as the SDGs and the UMF is widely acknowledged in the literature[31,52,53]. For example, citizen science can also play a key role in the achievement of these frameworks by raising awareness of global sustainability issues and mobilizing collective action[54]. Moreover, citizen science can promote attitude and behavioral change[55] and foster more democratic decision-making[56], especially by empowering marginalized groups that are often excluded from traditional data sources[57]. However, like any data source, citizen science has limitations. For instance, while citizen science has the potential to engage a more diverse range of participants, including marginalized communities, poor design of engagement methods can hinder this goal and amplify existing disparities[45]. For example, Pandya et al.[58] found that, in the United States, participation in citizen science activities does not reflect the broader population demographics. Historically marginalized groups due to race or ethnicity tend to participate less than majority groups. Additionally, studies show that men are more likely to participate than women, white participants are more likely to engage than those from other ethnic backgrounds, and participants often have at least one educational degree[59–61]. Another limitation of citizen science is the potential for bias, as data are often collected opportunistically, which may lead to issues such as oversampling in certain locations or time periods and undersampling in others[48]. Additionally, recruiting and retaining participants remains a significant challenge in citizen science[41]. Additional limitations may arise depending on the project type and design. To overcome these challenges, it is important to promote diverse participation through inclusive strategies, ensure data accuracy through strong data management practices, and maintain transparency in all stages of the projects, from design to the documentation of results.

Finally, citizen science holds great potential in gathering perception-based data, which is particularly important for monitoring urban sustainability and quality of life within the UMF and beyond. Traditional indicators rely on quantitative metrics, but factors such as liveability, accessibility and well-being require community-based insights to represent local realities. Implemented by UN-Habitat and sponsored by the Quality of Life Program, the Quality of Life Index, which includes both global and local indicators, is an example of how citizen science and perceptions can be integrated into monitoring frameworks[62]. This index and the initiative take a holistic approach, moving beyond traditional metrics like GDP to focus on human experiences and values, offering a two-layer measurement tool that allows cities to monitor aspects of urban life across multiple domains. Integrating citizen science in the methodology development process of the Quality of Life Index shows immense potential for citizen science to be widely used in sustainability monitoring, empowering communities to actively participate in shaping their urban environments. This presents an opportunity to harness the potential of citizen science data to advance sustainable development agendas. From a policy and science-policy interface perspective, it is essential to institutionalize the role of citizen science within urban monitoring frameworks and decision-making processes. Ensuring that local communities are at the heart of shaping safe, inclusive, resilient and sustainable cities requires sustained engagement with policy actors to build recognition of the relevance, reliability and value of citizen science data. Strengthening collaboration between scientists, policymakers, and citizens can promote more participatory, transparent, and accountable urban governance. Ultimately, embedding citizen science into policy frameworks is not only critical for addressing data gaps but also for ensuring that urban policies are grounded in local realities and responsive to community needs.

Methods

The methodology consists of a systematic review of the 77 UMF indicators and a subsequent search for citizen science projects that could provide data for their calculation, drawing entirely on secondary data. A five-step approach was implemented (Fig. 6), which follows the methodology applied in previous studies[29,30] and is outlined in detail below.

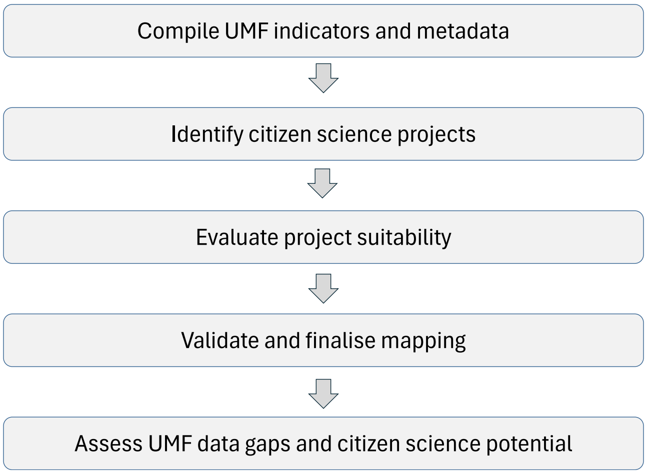

Fig. 6 | Process for mapping citizen science contributions to the UMF. Methodology for mapping potential citizen science contributions to the UMF indicators.

Step 1: Compile the UMF indicators and metadata

First, the UMF indicators were compiled and then cross-referenced with prior studies mapping citizen science contributions to the SDGs and the WHO's Triple Billion Targets[29,30]. This allowed us to highlight overlaps between the UMF and the SDG indicators, as well as identify indicators that are covered in the UMF but are not included in the SDG framework.

The metadata for each indicator was reviewed in detail to determine the relevant aspects and data requirements for indicator computation, as outlined in the UMF[11]. This step was critical for identifying potentially suitable citizen science projects and initiatives. The composition of indicators varies greatly in terms of the number of relevant variables, the complexity of computation, and the quality and amount of additional information recommended or considered beneficial for providing a more nuanced understanding of a given situation. All the UMF indicators covered in this study along with the relevant aspects of the mapping results from previous studies are presented in the Supplementary Information.

Step 2: Identify citizen science projects

A systematic search for relevant citizen science projects was conducted using academic databases (Web of Science and Google Scholar), general search engines (Google), and AI-assisted tools (ChatGPT 4.o). The search language was English. The search terms and keyword combinations consisted of a range of relevant indicator terms as well as search terms related to citizen science, such as "indicator term" AND "indicator term" AND "citizen science term". For example, for indicator 1.3.3. (mortality rate (suicide)), the indicator terms included "suicide", "suicide risk" and "mental disorder". The citizen science-relevant terms used across all indicators included "citizen science", "crowdsourcing", "citizen-generated data", "community-based monitoring", "participatory monitoring", and "volunteered geographic information", among others, reflecting the interchangeable use of these terms in the literature. ChatGPT was also used in this study to explore its potential for identifying additional projects that could otherwise not be detected through the search method described above. Any result provided by ChatGPT was carefully reviewed and validated through additional internet and literature searches before being used in this study. Overall, ChatGPT helped find some relevant projects that other search engines could not. For example, ChatGPT was fed with the following prompt: "Can you give existing examples of citizen science projects about income, or household income?" and it provided two results: (1) Our Financial Diaries (Australia): Conducted by the National Australia Bank (NAB) and the Centre for Social Impact: NAB Financial Diaries Project and (2) U.S. Financial Diaries: Conducted by the Financial Access Initiative and Innovations for Poverty Action in the United States: U.S. Financial Diaries Project. While it was not possible to find or verify the first example via an internet search (hence, not included), the second example was an existing project that could be considered as citizen science, with an associated link to a project website (hence, included in the analysis). Moreover, the ChatGPT results highlighted the "Financial diaries" method, which allowed further searching and the finding of additional relevant projects, including the Canadian Financial Diaries Research Project, the Hrishipara/Gojo Diaries, the Money Diaries (Australia) and the Microfinance Opportunities Financial Diaries. None of the other search engines using relevant search terms led to any of these or other similar projects.

Step 3: Evaluate project suitability

Step 3 consisted of two distinct activities of (a) determining whether a project qualifies as citizen science and (b) evaluating the level and type of contribution to the UMF indicators.

Step 3a: Determine citizen science relevance

We adopted a broad and inclusive definition of citizen science to determine whether an initiative's data and knowledge generation activity would qualify as citizen science. Our assessment is overall rooted in delineations stemming from the field of citizen science, such as ECSA's 10 Principles of Citizen Science[22], ECSA's Characteristics of Citizen Science[63], or the CitSciDefinitions[64], as well as relevant discussions in the literature[19,65]. For instance, in line with our inclusive definition, projects were considered eligible for inclusion if they aligned with key ECSA principles, more specifically: (i) the active involvement of citizens in scientific endeavors with meaningful roles as contributors, collaborators or project leaders, and (ii) the generation of genuine scientific outcomes or new knowledge. Aligning with the previous mapping study[29], we have excluded those initiatives where participants were paid salaries, even if the project was framed as "citizen science" or used other associated terms such as "community-based monitoring," as salaried participation constitutes formal professional engagement rather than voluntary involvement. However, we did include projects where participants received small incentives. Cases where the nature of participant incentives could not be clearly determined were excluded from our mapping. Activities were included if they aligned with terms distinct to certain research domains (e.g., crowdsourcing and volunteered geographic information from business-oriented, Earth Observation and geography studies, and community-based monitoring from developmental research). We also used the term of citizen-generated data from the international and global policy context as a reference point[18,66]. Citizen-generated data can be considered as "data that people or their organizations produce to directly monitor, demand, or drive change on issues that affect them[67]" often organized and managed by civil society groups[66]. If data collection activities were led by National Statistical Offices (NSOs) or other governmental agencies, we only included them if they could demonstrate that volunteers were actively engaged in one or more stages of the data value chain, such as the data collection, processing, analysis, use and impact, among others, such as the Community-Based Monitoring System in the Philippines. Furthermore, we also included projects that conduct participatory research activities using different terminology (e.g., "citizen-led assessments"[68], "peer research"[69], etc.) as well as projects that could demonstrate the active involvement of the public in data collection in a transparent way by clearly articulating the purpose and methods of data collection and the use of the data collected. Finally, projects were also considered if they conveyed an emancipatory attitude towards empowering or giving voice to a specific actor group, as essential holders of knowledge and co-researchers, as opposed to treating them mainly as research subjects. In this regard and although they mainly rely on conventional survey design and methods, projects such as the Youth Voice Census, the Trevor Project and the Mother's Survey were identified to be relevant (see Supplementary Table 1 for links to these projects). For example, the Youth Voice Census is the largest survey of youth voice and insight in the UK, where young people share their perspectives and offer an in-depth understanding of their experiences, aspirations and challenges. Likewise, the Mother's Survey was co-developed by a working group of affected unpaid caregivers, collecting information and perspectives from other caregivers.

Step 3b: Evaluate contribution to UMF indicators

Projects and initiatives were categorized based on their alignment with UMF indicators and associated metadata into three groups: (1) "already contributing," (2) "could contribute," and (3) "no alignment." "Already contributing" means a certain project is already providing data to the monitoring of a UMF indicator or to a similar SDG indicator, and these data are already being used or were used in the past by a reporting agency such as an NSO or a local authority. "Could contribute" refers to the cases where relevant data and information can potentially support the monitoring of a UMF indicator, based on the potential of data and information gathered; however, this potential has not yet been realized. Finally, "no alignment" describes situations where no relevant projects or initiatives aligning with the data requirements of an indicator are identified. Furthermore, both actual (already contributing) and potential (could contribute) contributions were analyzed to determine whether their contributions are "direct" and/or "supplementary". *Direct* contributions mean that the information and data gathered directly meet the requirement for an indicator variable. For example, Moovit and BusMap Project Lebanon can provide direct data contributions to indicator 1.2.2 (access to public transport in terms of location of stops and routes). These locations are required to calculate so-called service areas, which are essential to determine the indicator-specific variable "total population within the merged service areas for low and (or) high-capacity public transport stops". *Supplementary* contributions refer to information and data gathered by a project or initiative that can complement and provide additional information, especially when contextual and more nuanced factors or limitations of indicator calculations are outlined, and mitigating strategies are proposed in the indicator metadata. For example, the indicator 2.2.3 (use of public transport) note under "comments and limitations" that monitoring non-motorized trips and non-formal transport/paratransit is important. Although not part of the indicator itself, they are highly recommended as additional measures that current common approaches do not capture. This is why projects such as Strava Metro, GeoVelo, Moovit and BusMap Project Lebanon have been added as supplementary contributions to our mapping. Strava Metro and Geovelo are based on crowdsourcing and provide data about non-motorized trips. Moovit and BusMap Project Lebanon are community-based mapping initiatives to map transport systems including non-formal transport and paratransit options.

Projects and initiatives were considered as "could contribute" if relevant data and insights were gathered, while they were excluded if no indication about relevant data gathering with and by citizens was found. For example, projects that map alternative and free food sources to improve food access (e.g., foodoasis.la, baltimorefoodshed.com, foodfinder.us) were not included under indicator 1.3.6 (food insecurity). Even though many of them are based on community-mapping and provide valuable information in the context of food security and food access, they do not provide data or insights on people's experiences of food insecurity, which is the focus of this indicator.

Another relevant factor that was considered relates to the timing of projects and initiatives. Past projects and initiatives were also considered and potentially included if they could demonstrate that a citizen science approach had already been used to address topics relevant to an indicator. For example, related to the same indicator as above, Streetwyze/EatSF (see Supplementary Table 1 for project links) collected input from, and gave voice to, homeless and transient community members through workshops and meetings on the topic of food insecurity and affordable food access. Although the project is now finished (with Streetwyze supporting many other local initiatives), it was included as a suitable project. It still offers an example for how citizen science approaches could contribute both direct and supplementary contribution to the indicator, focusing on the most vulnerable sub-groups in society.

Our assessment relied largely on descriptive project information about the methods used, data collected and any relevant outputs, such as reports. Access to the data collected was found to be generally limited, and hence no assessment was made of the data itself, or its quality and suitability.

Step 4: Validate and finalize mapping

Once all 77 indicators were reviewed, the findings were cross validated by co-authors, which included domain experts from UN-Habitat to ensure consistency and accuracy. Feedback was incorporated, and additional potentially relevant citizen science projects suggested during this process were included in the mapping, following the methodology outlined in Step 3. A small number of cases (i.e., less than 7) prompted discussion regarding whether the projects aligned with the study's adopted definition of "citizen science." These cases were resolved collaboratively through shared documentation and email correspondence among the lead- and co-authors, with consensus reached in all cases. The validated results were then compiled into a structured dataset (Supplementary Table 1) for further analysis, identifying UMF indicators that could benefit from citizen science contributions, including those previously unaligned in earlier mappings.

Step 5: Assess UMF data gaps and citizen science potential

The Urban Monitoring Indicators Combined Dataset (UN-Habitat, September 2024) was analyzed to identify major gaps in UMF indicator reporting across 466 cities. These gaps were examined in terms of geographic coverage, thematic domains and scale of reporting (i.e., city, subnational, national). The citizen science mapping results were then compared with these gaps to determine where citizen science data could provide the most value, either by supplementing existing data sources or filling critical gaps in monitoring efforts. Detailed results from this analysis are provided in the Supplementary Information.

Data availability

All data generated or analyzed in this study are available within the Supplementary Information. The compiled dataset of UMF indicators, metadata, and the mapping of citizen science contributions is provided in Supplementary Table 1. The UMF Indicators combined dataset (UN-Habitat, September 2024) used to assess reporting gaps across 466 cities is publicly available from UN-Habitat (https://data.unhabitat.org/pages/urban-monitoring-framework). Additional details on individual citizen science projects, including links to project websites, are also included in the Supplementary Information.

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Author contributions
I.M. and D.F. contributed equally as first authors. I.M. conceived the original idea. I.M. and D.F. compiled the UMF indicators and aligned them with previous mapping efforts. I.M., D.F., L.S., and G.H. reviewed the UMF indicators and did the mapping with citizen science projects and other relevant initiatives, which were then checked by D.F., R.N., and D.M. D.F. further validated the results and modified the mappings. The results were analyzed and turned into figures by I.M., and further refined through discussions with D.F., L.S., and G.H. The initial draft of the paper was undertaken by I.M., D.F., L.S. and G.H., with further contributions from R.N. and D.M. All authors read and approved the final manuscript before submission.

Competing interests
The authors declare no competing interests.

Additional information
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