Mapping the Landscape of Citizen Science in Africa: Assessing its Potential Contributions to Sustainable Development Goals 6 and 11 on Access to Clean Water and Sanitation and Sustainable Cities

CITIZEN SCIENCE: THEORY AND PRACTICE

COLLECTION: CONTRIBUTIONS OF CITIZEN SCIENCE TO THE UN SDGS

RESEARCH PAPER

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ABSTRACT

Data are vital for and creating knowledge-based solutions to development challenges facing Africa. As a result of gaps in government-funded data collection, and in the interest of promoting community engagement, there is a global movement towards consideration of nontraditional sources of data, including citizen science (CS) data. These data are particularly valuable when collected at a high resolution over large spatial extents and long time periods. CS projects and infrastructure are abundant and well documented in the Global North, while needs for participatory projects to fill environmental monitoring gaps may be greater in the Global South. The paper explores the contributions of citizen science projects originating in Africa for two Sustainable Development Goals (SDGs), namely SDG 6, and SDG 11 which are particularly important to the millions of low-income residents of cities across Africa. Using a mixed methods approach that involves online surveys, interviews, expert conference panels, and a desk review, we analyze a total of 53 CS projects focusing on water, sanitation, and urban planning. The paper addresses CS in Africa and CS for SDGs, and documents evidence for participatory and CS data collection in Africa. It also describes the survey methods, including approaches to training of volunteers, sources of funding, data collection methods, and objectives of the tools and projects. Finally, it provides reflections on the challenges of integrating CS into official statistics in Africa, and some lessons learnt from CS projects in Africa. This paper recommends the establishment of an open-source database, creation of a network of CS projects for communication and collaboration, the uptake of citizen-generated data, and continuous funding for such projects in Africa.

KEYWORDS:
Africa; citizen science; participatory data; data governance; knowledge-based solutions; Sustainable Development Goals; water; urban

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INTRODUCTION

Data are vital for informing decisions and creating knowledge-based solutions to development challenges facing Africa. There is growing awareness of the potential for citizen science data to fill data gaps and improve the basis for decision-making (Wehn and Almomani 2019). Citizen science (CS) as a field comprises different ways to engage citizens in the collection and analysis of data, ranging from local projects involving fieldwork and data collection (Andrianandrasana 2016) to broad-scale efforts to crowdsource data through internet-based platforms (e.g., volunteeeographicapic information) (Murindahabi et al. 2018; Braz Sousa et al. 2022). CS efforts have the potential to provide fine-resolution data over large spatial extents and long time periods. CS projects and infrastructure are abundant and well documented in the Global North, yet there is comparatively less information about such projects in the Global South (Danielsen et al. 2014), despite their significant potential to fill data gaps and to contribute to reporting on sustainable development goals (SDGs) (de Sherbinin et al, 2021; Croese, 2021). CS efforts can inspire people to collect data about local issues, to inform, act, and make decisions that speak to their own experiences (Open Air Laboratories [OPAL] 2014; Paul et al. 2014; Stevens et al. 2013; Blossom 2012; Fernandez-Gimenez and Ballard 2008; Danielsen et al. 2022). Tracking and monitoring performance of the SDGs and other international development frameworks in Africa such as the New Urban Agenda (https://habitat3.org/the-new-urban-agenda/) requires evidence that these novel approaches are fit for use, equitable, and inclusive.

This paper was commissioned by the International Science Council's (ISC's) CODATA-World Data System Task Group on Citizen Science for the SDGs (henceforth CODATA-WDS TG) (Hultquist et al 2022; de Sherbinin et al. 2021; Cooper et al. 2021; Bowser et al. 2020), which studied the feasibility of aligning the data generated by CS projects and platforms to the specific requirements of the Result Framework proposed by the United Nations (UN) 2030 Agenda (United Nations 2015). This alignment would facilitate and encourage the inclusion of such data in the official monitoring of the SDGs at local, national, and global levels.

This paper aims to map the landscape of CS projects in Africa and their contributions to SDGs 6 and 11 to demonstrate their potential as data sources that are fit for use, equitable, and inclusive. It also makes an important contribution by filling knowledge gaps about CS projects in Africa. There is a dearth of information on CS projects in many subregions of Africa—for example, Africa-specific projects are notably absent from major databases such as SciStarter (https://scistarter.org/)—and, therefore, there is a limited basis for understanding their potential contributions to tracking and monitoring SDGs.

This article begins with sections addressing CS in Africa and CS for SDGs, and documents evidence for participatory and CS data collection in Africa, especially for SDGs 6 and 11. We then proceeded with a description of the survey methods, followed by a review of the CS projects, including approaches to training volunteers, sources of funding, data collection methods, and objectives of the tools and projects. We also provide reflections on the challenges of integrating CS into official statistics in Africa, and some lessons learnt from CS projects in Africa. The paper concludes with some recommendations on the way forward.

CITIZEN SCIENCE IN AFRICA AND FOR THE SUSTAINABLE DEVELOPMENT GOALS

The term "citizen science" is widely used to denote voluntary participation of citizens in scientific data gathering and/or analysis (Donnelly et al. 2014; Dickinson et al. 2012; Roy et al. 2012; Conrad and Hilchey 2011). Until the late 19th century, there were no professional scientists as known today (Kight 2012; Miller-Rushing et al. 2012). Research was typically undertaken by amateurs, those without professional occupations, often known as Gentlemen of Leisure (Miller-Rushing et al. 2012), especially upper-class men with time for educational and scientific pursuits. There are accounts of individuals such as Charles Darwin, considered a naturalist, geologist, and biologist (Kight 2012; Dillon 2014), and Carl Linnaeus, a Swedish botanist and physicist, who worked with a wide network of citizen volunteers who sent samples to them for analysis, a not-uncommon practice at the time (Scyphers et al. 2015). Thus, CS is not a new phenomenon. But with the advent of the internet and smartphone-based data collection tools the number of citizen scientists and the scope have grown significantly, from a mostly Western to a worldwide phenomenon, and from a purely natural-science focus to projects that address almost every aspect of the environment and human endeavor (Fraisl et al. 2022; Reyes-García et al. 2022).

Because some of the roots of CS are in enlightenment thinking and in Western traditions, the ways that CS is translated in African contexts bears some exploration, though this is largely outside the scope of this paper. What can be said is that in the past 40 years, a second strand of CS has focused on environmental justice (Ceccaroni et al. 2021; Haklay and Francis 2017). This strand emerges at the interface of political activism and volunteering as a social action. It is found in self-help, collectives, or community-driven efforts over environmental or societal concerns, and represents a social outcry as well as a search for local solutions (Cohn 2008). It is this strand that has greater resonance in the African context, insofar as it is action oriented and focused on highlighting community needs (Tengö et al. 2021). Seen in this light, CS has the potential to generate social capital required for collective action, to solve a local problem, and to resolve large-scale environmental problems (Overdevest and Orr 2004). It ensures public participation and inclusion, social learning and behavioral change, self-awareness and call to action, which are often neglected in traditional approaches (Lowry and Fienen 2013; Conrad and Hilchey 2011). Thus, CS as a social development tool is a strategy for achieving good governance and human rights (Gaventa and Barrett 2012). In political economy, CS is seen to promote democratization of information to encourage debates and to improve decision-making (Ostrom 1990; Overdevest and Orr 2004; Macknick and Enders 2012).

Some experts have proposed the value of including CS data in the reporting process of the SDGs (Fraisl et al. 2020; Fritz et al. 2019; Flückiger and Seth 2016; IAEG Secretariat 2014). However, there is insufficient evidence to demonstrate where CS currently contributes or where it could contribute to this reporting in Africa. This is the aim of this paper.

Whereas early forms of CS may have been part of a colonial agenda (e.g., many amateur scientists worked hand-in-glove with colonial administrators to carefully document the plants and animals in their new realms), it now holds the potential to support the measurement (and hopefully attainment) of the SDGs, and to increase justice, in countries that have long legacies of colonialism (Corburn et al. 2022). The UN Agenda 2030 pledges to “leave no one behind” and aims at including marginalized groups (Ramalho and Guarneri 2022). Marginalized populations suffer exclusion as part of their everyday life experience in terms of access to basic services, opportunities to enhance their conditions, and participation in the process of decision-making (Thunyane and Christine 2019). One dimension of marginalization occurs when knowledge generated by marginalized groups is not used for decision-making or where they lack data access and/or are refused the opportunity to contribute data to solve local issues (Thunyane and Christine 2019; Fraisl et al. 2019; GPSDD 2017). Forms of marginalization, according to Thunyane and Christine (2019), include unknown voices, which describes those overlooked in social surveys and data collections; silent voices such as the destitute, the weak, and the vulnerable; muted voices including marginalized communities, low-skilled migrant workers, and refugees; and the unheard voices such as those digitally disconnected.

There is a growing number of efforts to engage marginalized populations in data collection. For example, Slum Dwellers International (SDI) routinely compiles data collected by those who live in slums, and has so far profiled close to 8,000 slums on the “Know Your City” website, and produced a report by the same name (SDI 2018). The report identifies the flawed assumption that planning can be done for informal settlements without data and without consulting local residents.

Similarly, the nonprofit organization CIVICUS produced a report *Acting Locally: Monitoring Globally* which focused on citizen-generated data for the SDGs (Jameson et al. 2020). The authors note that there is often a mismatch between citizen-generated data (CGD) and SDG monitoring because: 1) CGD has more focus on local action than high-level policy-making; 2) CGD tends to focus on SDG targets rather than indicators, using different units of analysis; and 3) CGD can deliver contextual information to drive progress around SDGs even though they may not contribute directly to indicator development. An example of CGD is data from water point mapping in Malawi, which was used by the nongovernmental organization (NGO), WaterAid, to advocate for new water points in under-served communities (Gray et al. 2015). Finally, ISC (2020) highlights the potential to co-produce transdisciplinary knowledge on sustainable urban development in Africa, through collaboration between scientists, policy actors, urban practitioners, the private sector, and communities (Elias and de Albuquerque 2022).

Elsewhere, MacFeely and Bostav (2019) argue that unofficial statistics from NGOs and community-based organizations (CBOs) need to be taken into account, and indeed are vital, insofar as national statistical offices (NSOs) are unable to collect all the data needed to monitor the SDGs (K’Akumu 2023). This is in line with Fraisl et al. (2020) and Fritz et al. (2019), both of which assess the potential for CS data to fill important gaps in the monitoring and reporting of progress toward SDG targets, and argue for greater acceptance of such data within official UN and national government reporting efforts. However, our results suggest that there is not yet much uptake of CGD data for SDG reporting in the CS projects we surveyed.

Lack of attention to community voices (Thunyane and Christine 2019) and CGD (forms of data apartheid) may lead not only to insufficient approaches to SDG reporting in Africa but also to poor decision-making and approaches to SDG reporting in Africa. Citizen scientists currently play active roles in a wide range of urban (SDG 11) and water, sanitation, and health (WASH) (SDG 6) projects, which can contribute to the collection of data for reporting quite easily and potentially at lower cost than conventional data official collection streams.

METHODOLOGY

Our research design involves both qualitative and quantitative approaches to collect and analyze the data on African CS projects. The CODATA-WDS TG first held discussions to agree on the choice of the SDGs on which to focus, with the decision to focus on SDGs 6 and 11 emerging from considerations of topics of greatest urgency to African communities (Berisha et al. 2022) in consultation with ISC's Leading Integrated Research for Agenda 2030 in Africa (LIRA2030), which focuses on accomplishing the SDGs in African cities. This was followed by the design of an online survey (Supplemental File 1: Appendix A), which was deployed using a Google form in both English and French. Task Group members sought to identify as many CS projects as possible across the continent through personal contacts in the CS community in the region and an Internet search for relevant projects. Several issues were encountered in the process as several projects found online had obsolete websites without current contact information. Several CS projects were contacted without response. The availability of the survey was extended to accommodate more responses; however, some did not answer at all while some said that they would need permission from their management and never submitted the form. Aside from the survey being primarily web-based, some were administered via WhatsApp messages. We also scheduled convenient times for the organization's representatives to answer survey questions via a phone call. For some respondents, they are working on multiple CS projects, and to avoid duplication of the results, only one CS project was recorded per respondent. In total, the team contacted 102 CS projects in Africa, out of which there were 53 adequately filled responses, or a 52% response rate. A full list of projects by region and by SDGs addressed is provided in the Supplemental File 1: Appendix B.

To corroborate and supplement our findings, the Task Group convened two panel sessions at international data conferences, which brought together experts such as CS project leaders, practitioners, and researchers across Africa. The first panel session was held on 2 December 2020 during the International FAIR Convergence Symposium and addressed two topics: (i) the relevance of CS projects in Africa to the SDGs, and (ii) the future of CS projects in Africa. Two participants, one from Map Kibera located in Nairobi, Kenya, with interest in Slum Community Profiling, and WaterAid, focusing on Rural Water Supply Monitoring located in South Africa, contributed to the Community perspective. Two CS project leads, which are WATSAN in Kibera, Kenya and the People's Dialogue for Human Settlements in Accra, Ghana, gave their perspectives on SDGs 6 and 11 respectively. Similarly, two panelists (Citizen Science Africa Association, Nairobi, Kenya and the Institute of Global Sustainable Development, University of Warwick, UK), representing practitioners and researchers, respectively, focused on the indicators and research perspectives. A panelist from CIVICUS & DataShift gave an overview of the role of citizen science–generated data in tracking and monitoring of SDGs in Africa, while the representative of the ISC provided a funders' perspective.

The second panel session, titled "Bridging Service Gaps: UN Sustainable Development Goals and Guidelines for CS Generated Data in Developing Countries," was held on 23 June 2022 at the International Data Week in Seoul, South Korea (Table 1). Six panelists participated virtually. They focused on a wide range of themes including sanitation,

THEME	ORGANISATION	TOPIC
Keynote	Citizen Science Africa Association	Overview of CS in Africa
Sanitation	Gather Hub	Decolonising data: supporting municipalities to improve the ownership, diversity, and accessibility of sanitation data
Water	Kinara Youths for Evolution (KYE), Tanzania	Win-Win-Win Partnership by Using Data for Improved Water Services
Resilience Action Plan	Shanty Town Empowerment Foundation (SHEF) and Nigeria Federation of Slums/Informal Settlements (NSISF)	Partnership for Data: Developing Coastal Community-Level Resilience Action Plan in Lagos, Nigeria
Open Data in CS	North Carolina State University, Raleigh, NC, United States	A Co-Created Data Governance Toolkit for Addressing Ethical Dimensions of Citizen Science
CS Data for the SDGs	CODATA Task Group on CS for the SDGs	Citizen Science Guide for the United Nations Sustainable Development Goal Indicators

Table 1 Bridging Service Gaps: United Nations Sustainable Development Goals (SDGs) and Guidelines for citizen science (CS)–Generated Data in Developing Countries at the IDW/SciDataCon 2022 (June 23, 2022).

Source: https://www.scidatacon.org/IDW-2022/sessions/303/.

water supply, resilience action plan, open data in CS, and CS Data for the SDGs. The conversations formed the basis for the SWOT analysis and qualitative data used for this paper.

The final activity involved the analysis and presentation of findings for feedback from the CODATA Task Group.

The authors identified and mitigated privacy and safety concerns throughout the data collection. Generally, participants were required to give an informed consent in writing or verbally before filling questionnaires, granting interviews, or participating at workshops. The authors also ensured minimization of personal information and prevention of data identification. For instance, all data collected were processed and stored in a way that is not possible to restore it to the original format that would make personal identification possible.

RESULTS

GEOGRAPHIC REPRESENTATION OF CITIZEN SCIENCE PROJECTS SAMPLED

The sample survey comprised a total of 53 CS projects involving 30 for SDGs 6 and 23 for SDG 11, respectively. Further analysis shows that two CS projects from Central Africa, 13 from Southern Africa, 16 from East Africa, and 22 from West Africa were surveyed (Supplemental File 1: Appendix B). Despite a concerted effort to collect data on projects in both anglophone and francophone Africa, the difficulty of finding contacts (respondents) for projects was compounded by the relatively low response rate, which meant that our sample over-represented some regions (West, East, and Southern Africa) and under-represented others (e.g., francophone Africa and North Africa) (Supplemental File 2: Figure 1). The most represented countries included Nigeria, Kenya, and South Africa, a reflection of the contacts available to the Task Group.

BENEFITS OF THE CITIZEN SCIENCE PROJECTS SAMPLED

CS projects are usually designed to benefit the community. Table 2 shows the number of projects by region and their stated objectives or outcomes. The analysis of the outcomes and/or benefits of the 53 CS projects as reported by the CS project organizers shows that they were mostly established to advance research (27), educate the public (23), ensure that informed policies are enacted (11), and to capture data from end users (10). The survey reveals that data collection, reporting, or monitoring of SDG indicators were not explicitly listed as a project purpose by sampled CS projects. Meanwhile, follow up conversations with project proponents suggested that uptake of data by NSOs or government agencies was also limited (see below).

There could be other, unstated reasons for the establishment of CS projects in Africa. For instance, CS practitioners who served as panelists at the conferences described a wide range of project purposes. A panelist reporting on data for improved water services indicated that "since 2019, our youth volunteers, called Community Change Agents (CCAs), have helped to resolve 1,860 leaks, 52% repaired within two weeks, contributing to an increase from 2.73 (April 2019, 10 wards) to 3.57 (July 2021, 16 wards) days of water per week." According to SHEF, although their primary goal is to empower urban poor through savings schemes, they use community profiling to collect data for advocacy and negotiation of their common aspirations. Similarly, Kinara Youths for Evolution (KYE) uses a free online platform for data collection and analysis to resolve pipe leakages. Further analysis of the perceived benefits of CS projects according to the subregions indicates that in West, East, and Central Africa the aim is primarily to educate the public and advance research; whereas in Southern and Eastern subregions they aim secondarily to capture data from end users.

SUBREGION	PERCEIVED BENEFITS OF CITIZEN SCIENCE PROJECTS				
	EDUCATE THE PUBLIC	CAPTURING DATA FROM END USERS	ADVANCE RESEARCH	ENSURE INFORMED POLICIES ARE ENACTED	OTHERS
North Africa (n = 1)	1	0	0	0	0
West Africa (n = 14)	6	2	9	1	2
Southern Africa (n = 10)	5	4	5	1	0
Central Africa (n = 9)	4	1	5	2	1
East Africa (n = 19)	6	3	8	7	1
Total	23	10	27	11	4

Table 2 Respondents' perceived benefits of citizen science projects in Africa (n = 53, multiple responses possible).

TOOLS AND METHODS OF CITIZEN SCIENCE PROJECTS IN AFRICA

Table 3 presents tools used for generating and communicating information, and the frequency of each usage. We found that the CS projects in our sample mostly used smartphones (77.4%; *n* = 53). Data visualization is the next commonly used technique (62.3%). A data visualization example is website portals and dashboards where data can be stored and extracted by users. Guidebooks are also frequently used (54.7%). The guidebooks used by the CS projects include map books, street guides, and tourist guides, and they are typically used to educate participants on their roles, project management, communication, application of FAIR principles, use of data, and knowledge gained from CS. Less frequently used tools were computers, test kits, sensors, online survey forms, and modeling landscapes and GIS. Some possible reasons for this may be because these tools require some form of training, people may have poor internet access, and these modern digital technologies are often beyond the reach of the urban poor.

APPROACHES TO TRAINING VOLUNTEERS

In every field of research, the capability and the efficiency of field workers affects the quality of the data collected. Our results show that 86.8% had a field-based training and pilot test (Table 4). But perhaps heightened by COVID-19 restrictions, virtual training of volunteers was also common (54.7%). Classroom training and other forms of training were slightly less adopted, each with 43.4% of volunteers participating in training using this approach.

Primary contributions of sampled citizen science projects in Africa

The contribution of CS projects to SDG 6 includes water supply and water quality assessment, solid waste management and sanitation systems, and disease and health services. Similarly, the contributions of CS projects to SDG 11 include mapping of urban ecosystems and resources, city planning, transportation, protection of poor and vulnerable people, disaster risks and resilience, and city policy formulation. These underline their critical importance.

TOOLS	NUMBER	PERCENT (OF 53 CS PROJECTS)
Smartphone	41	77.4%
Computer	20	37.7%
Data visualization	33	62.3%
Guidebooks	29	54.7%
Test kits	22	41.3%
Sensors	21	39.6%
Online forms	8	15.1%
Modeling landscape and GIS	4	7.5%
Others	1	1.9%

Table 3 Tools used in the African citizen science (CS) projects (n = 53 CS projects; multiple responses possible).

APPROACHES	RESPONSES	
	NUMBER	PERCENT (OF 53 CS PROJECTS)
Virtual training	29	54.7%
Field based training pilot test	46	86.8%
Classroom training	23	43.4%
Other training.	23	43.4%

Table 4 Approaches used to train volunteers in the African citizen science (CS) projects (n = 53 CS projects; multiple responses possible).

Consequently, we analysed the sampled CS projects in Africa by the year they were established for one decade (2008–2019) (Supplemental File 3: Supplemental Figure 2) to validate the assumption about their potential contribution to SDG tracking and monitoring. The result reveals minimal additions of CS projects from 2008 to 2015, except 2009, which had six. However, there were higher number of CS projects established from 2016 to 2019, with seven in 2017 and eleven in 2019. In all, the survey shows their increasing recognition, with 32 sampled CS projects in Africa established in four years.

Besides the potential for bias in our sample, there are two hypotheses for the larger number of established projects in the latter part of the period: It could be that CS has only recently caught on in many regions of Africa, or it could suggest that funding vicissitudes for CS projects in Africa means that projects are of relatively short duration, with projects from earlier years already having ended by the time of the survey.

FUNDING OF CITIZEN SCIENCE PROJECTS

Table 5 shows the different sources of funding. The highest percentage of projects (each with 24.5%) rely on in-kind institutional support from the hosting organization or they do not have access to funding at all, suggesting that much of the work is done on a volunteer basis. About 22.6% depend on public-private partnerships (PPPs) to implement their initiatives. Seventeen percent receive support from donor organizations, such as the UK National Institute for Health Research and SDI, among others. The data also show that CS projects access funds from government budgetary allocations (15.1%). Lack of funding may affect operations and long-term sustainability.

DATA COLLECTION APPROACHES

Table 6 shows the results for the methods employed by the sampled CS projects in Africa. The most popular method of data collection by the CS projects (n = 53 CS projects) is direct observation (73.6%). This was followed by participant observation (54.7%), social surveys (52.8%), interviews (47.2%), expert opinion (39.6%), and focused group discussion (FGD) (11.3%). The least used method of data collection was synthesis of documents (3.8%), which may involve curating archival data. It is clear that the methods of data collection vary, which may be connected to the peculiarities of individual projects, levels of competences, and available resources.

CHALLENGES OF INTEGRATING CITIZEN-GENERATED DATA INTO NATIONAL STATISTICAL OFFICES

Integrating CGD into NSOs presents some challenges. Our respondents identified challenges such as power relations and institutional bureaucracies (24% each), the challenging process of data integration (19%), divergent interests of stakeholders (16%), and individual idiosyncrasies (6%). The contributions from the panelists show that most CS projects in Africa did not set out to generate data for the SDG indicators, hence collected data don't follow acceptable standards or validation to make them usable by NSOs. A panelist from SHEF opined that "driven by local challenges including poor sanitation, access to basic services, diseases, flooding, poor living conditions, CS projects are primarily concerned with improving their living conditions with CGD as evidence to engage or negotiate with authorities for a change." In this vein, Water Aid suggested that "data from water point mapping was used to advocate for new water points in under-served communities in Malawi."

TYPES OF FUNDING	NUMBER	PERCENTAGE (OF 53 CS PROJECTS)
Donors	9	17%
As part of active projects	5	9.4%
Direct fundraising	5	9.4%
In-kind institutional support	13	24.5%
Government budget	8	15.1%
Public-private partnership **(PPP)**	12	22.6%
Self-funding	1	1.9%
No funding	13	24.5%
Other sources	1	1.9%

Table 5 Sources of funding for citizen science (CS) projects (n = 53 CS projects with multiple responses possible).

METHODS OF GENERATING DATA	NUMBER OF RESPONSES	PERCENT (OF 53 CS PROJECTS)
Participant observation	29	54.7
Expert opinion	21	39.6
Focus group discussion	6	11.3%
Direct observation	39	73.6%
Interviews	25	47.2%
Social surveys	28	52.8%
Synthesis of documents	2	3.8%

Table 6 Methods of data collection by citizen science (CS) projects in Africa (n = 53 CS projects, multiple responses possible).

DISCUSSION: LESSONS FROM SAMPLED CITIZEN SCIENCE PROJECTS IN AFRICA

The following are the key lessons learned from the survey of CS projects in Africa and the two panel sessions, framed as a strengths, weaknesses, opportunities and threats (SWOT) analysis.

STRENGTHS

CS has the potential to:

- Provide inclusive and multifaceted data on thematic issues relevant for several SDG indicators. Examples include Map Kibera and Mathare, which collected data aligned with SDG 3 (Good Health and Well-Being), SDG 4 (Quality Education), SDG 6 (Water and Sanitation), and SDG 16 (Peace, Justice, and Strong Institutions). The SDI and the Nigeria Federation of Slums/Informal Settlements NSISF have created more than 8,000 slum community profiles on topics such as water, sanitation, and trash piles, and these profiles can provide data for several SDG indicators.
- Co-produce knowledge and enhance science communication. For instance, the creation of a dedicated website in the Map Kibera project was an opportunity for slum dwellers to access and contribute data on issues affecting slum communities from their own perspectives. The SDI representative added that "community people are open to new tools from paper to digital platforms such as the Tarrifa model, which enables community members to collect *in situ* data for dialogues, decisions, and negotiations with governments." This makes CS relevant for catalyzing change. Moreover, citizen-generated data are quicker

and easier to collect and update than other sources of data.

- Build bridges, trust relationships, and skills among citizens, NGOs, academics, and government through a transdisciplinary approach to harness multiple perspectives from everyday life experiences. This includes working with local organizations with relevant complimentary skills. For example, SDI integrates data collected by community mappers by leveraging the power of self-help organizations. In terms of skills, the mWater platform adopted by Kinara for Youth Evolution, a youth-led grassroots NGO in Morogoro, Tanzania, is used to track, identify, and fix pipe leaks to improve water services. This position was further buttressed by one of the panelists, who enumerated the ways in which science funders can enhance knowledge co-production with citizens by establishing "new place-based partnerships across different sectors and regions: to leverage existing expertise, skills, and resources."
- Enable the development of databases, through the application of phone apps for collection, processing and analysis, and dissemination (visualization) of data on urban spaces. These databases may enhance the integration of conventional data sources with big data, using social media platforms for their dissemination.
- Enable the creation of new metrics for monitoring and reporting on SDGs. For instance, the Map Kibera team combines data and storytelling to tell the stories behind numbers (www.voiceofkibera.org), and this effort catalyses local actions by identifying local challenges and co-creating local solutions.
- Enhance a sense of data ownership and social learning, and increase application of the FAIR principles. Our survey demonstrates the importance of the FAIR principles as it relates to CGD. The ability to integrate CS data with georeferenced data is expanding, and several examples of new applications and approaches are emerging, such as OpenStreetMap, photovoice, and KoboCollect.
- Increase the recognition of the valuable expertise of members of CS projects in such projects as beach clean ups, community profiling, resilient action, COVID-19 monitoring, and biodiversity mapping.
- Promote knowledge co-production to understand the environments and which actions are needed. In this regard, a panelist stated that CS supports "a better understanding of local needs and interests, to gain a holistic understanding of problems, socio-political aspects, and constraints, and to co-produce locally grounded knowledge and solutions."

WEAKNESSES

- Digital technologies are enhancing data collection and management but CS projects in Africa are limited in data collection in communities and geographical areas where access to technology and internet connectivity is low.
- Proper community engagement that drives CS monitoring based on local needs to capture multiple-stakeholder perspectives involves an intentional and time-consuming process to develop trust and to maintain the appropriate connections.
- CS projects are generally under-funded, and most of the available funds for CS in Africa are from external sources; this inhibits continuity and sustainable long-term monitoring, since the projects often stop when the external funding cycle ends.
- If the goal is the incorporation of CGD into SDG reporting, then NSOs may be reluctant to consciously curate, validate, standardize, and manage the process, which hampers the uptake of CGD for the SDGs.

OPPORTUNITIES

- Provides multiple perspectives. CS, such as the Map Kibera team, gives multiple perspectives, and enhances social learning and collective reflections including local insights and understanding about place-based issues.
- Mobilizes creativity and innovation. SHEF reported that their CS group developed a resilience action plan to address perennial flood issues in Ajegunle Ikorodu, a Lagos slum community. Similarly, Corburn et al. (2022) report on a CS project in Mukuru informal settlement in Nairobi to co-design environmental improvement solutions.
- Scalability of projects across sectors and settlements. The SDI has demonstrated how data collection and community development can grow progressively through community-based self-organizations and projects.
- Data ownership increases participation and commitment to addressing local issues and solutions as demonstrated in the WATSAN project in Nairobi and the KYE initiative for improved water supply.
- CS reduces inequalities and poverty in marginalized communities by putting issues on the map and disclosing place-based issues to draw government's attention to critical local needs.

THREATS

- The elements of data access and sharing in CS may in some cases expose data collectors and communities to

risks and harms such as discrimination, stigmatization, and evictions.
- Data that reveals personal details increases safety concerns among citizens.
- Some intended benefits of CS projects, if not balanced, may have negative impacts such as increased taxes, rates, or bills for things like improved water service.
- Insufficient funding and low organizational capacity limits continuity or the scaling up of CS projects.

CONCLUSIONS AND RECOMMENDATIONS

CS is a relatively new phenomenon in Africa when compared with other parts of the world, but the growing community of practitioners and number of CS projects are clearly making an impact and helping to better the lives of Africa's large and rising urban population. This paper provides evidence regarding where CS in Africa currently contributes, or where it could contribute data for tracking of SDGs 6 and 11. It examines existing CS projects and their potential contributions to the SDGs, and builds on two organized sessions by the CODATA-WDS TG on CS for the SDGs. There is a growing record of CS projects on water, sanitation, and sustainable cities in Africa, especially in East and West Africa, but there is still little evidence in other regions, especially in North Africa. Lack of awareness about CS projects in some subregions is a major barrier to showing the usefulness of CS projects to monitor and track SDGs in Africa. It is evident that networking is key and highly relevant for participatory data mapping for monitoring and tracking SDGs (Eicken et al. 2021).

Regular engagement and interaction among CS projects in Africa are necessary to enhance communication, collaborations, and partnerships. While we understand the need to have institutional approval to share, there should be avenues to provide vital information. Our hope is that CS projects in Africa will recognize the value of sharing, and benefit from learning about other projects.

Developing an Africa CS network for communication, collaboration, and community goals is the primary goal of the recently formed Citizen Science Africa Association. We hope that this organization will help to facilitate connections and to increase the openness of CS projects in Africa. It is also important to create a database of CS projects in Africa (Supplemental File 4), sorted according to SDGs, using an open repository to enhance identification and engagement to better monitor and track their contributions to the SDGs (Danielsen et al. 2013). This could guide researchers, universities, and funders about the contributions of CS project data to SDGs. However, CS projects should be established to collect data that intentionally aligns with SDG indicators and targets not merely to address local challenges.

DATA ACCESSIBILITY STATEMENTS

Data is available within the article or its supplemental materials but the detailed dataset can be accessed here https://www.ciesin.columbia.edu/data/cit-sci-sdgs-africa.

SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1:** Appendix A. Survey Instrument & Appendix B: List of Citizen Science Projects Surveyed. DOI: https://doi.org/10.5334/cstp.601.s1
- **Supplemental File 2:** Supplemental Figure 1 (Citizen Science Projects by African subregions). DOI: https://doi.org/10.5334/cstp.601.s2
- **Supplemental File 3:** Supplemental Figure 2 (Citizen Science projects by year established). DOI: https://doi.org/10.5334/cstp.601.s3
- **Supplemental File 4:** CODATA CITIZEN SCIENCE FOR THE SDGs AFRICA SURVEY DATABASE+March 2023. DOI: https://doi.org/10.5334/cstp.601.s4

ETHICS AND CONSENT

This article does not contain any studies with human or animal subjects performed by any of the authors.

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COMPETING INTERESTS

The authors declare that the research was conducted in the absence of any known commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

The conceptualization and methodology were led by PE; AS, AdeS, CH, FD, CC, EF, MD, and IP contributed to the design and data analysis; PE, AS, AdeS, CH, FD, CC, RM, EF, AB, JM, MD, and IP contributed to data interpretation, manuscript writing, and revising.

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