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Review Article

Challenges and Opportunities in Unlocking the Potential of Citizen Science in Zambia: A Review

Christopher Mulwanda[1*], Maggie Mapalo Mwape[1], Mainess Kandah Namuchile[2]

[1]*Centre for Environmental Justice, Plot 37741, Pitta Road, Off Twin-Palm Road, Ibex Hill, Lusaka, Zambia*

[2]*Department of Computer Science, School of Engineering and Technology, Mulungushi University, Zambia*

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ABSTRACT

Citizen science has emerged as a practical approach for generating large-scale environmental data and engaging communities in conservation. Globally, it has been integrated into biodiversity monitoring programs, particularly in developed countries, where it addresses data gaps and informs policy. In Sub-Saharan Africa (SSA), and Zambia specifically, adoption remains limited despite its potential to tackle biodiversity loss, such as pollinator decline. This paper explores the benefits of citizen science, the barriers hindering its implementation in Zambia and SSA in general, and opportunities for scaling it up. Key challenges include low public awareness, inadequate digital infrastructure, socio-economic constraints, and weak institutional frameworks. However, opportunities exist to leverage mobile technologies, foster partnerships among government agencies, NGOs, and academic institutions, and implement targeted capacity-building programs. Case studies from SSA, such as bird atlas projects and iNaturalist initiatives, demonstrate the feasibility and impact of citizen science when supported by robust protocols and community engagement. The paper concludes by proposing a roadmap for Zambia that emphasizes integration into national biodiversity strategies, investment in digital inclusion, and multi-stakeholder collaboration. Addressing these gaps can position citizen science as a transformative tool for biodiversity monitoring, conservation, and sustainable development across in Zambia.

*CORRESPONDING AUTHOR:

Christopher Mulwanda; Centre for Environmental Justice, Plot 37741, Pitta Road, Off Twin-Palm Road, Ibex Hill, Lusaka, Zambia: Email:mulwandachristopher0@gmail.com

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1. Introduction

Citizen science is broadly defined as the participation of non-professional scientists in scientific research, contributing to the generation of new knowledge and information [1,2]. It involves voluntary engagement in scientific processes, most commonly through data collection to monitor aspects of the natural world [3]. Increasingly, scientists view citizen science as a growing movement that enlists the public in discovery, monitoring, and experimentation across diverse disciplines [4,5]. Over the past two decades, entomologists and ecologists have shown heightened interest in what is now widely recognised as “citizen science.” This approach is inclusive, requiring neither formal scientific training nor employment in research institutions. The willingness of volunteers to collect and share scientific data offers significant appeal, particularly for large-scale monitoring efforts [2,6]. The term “Citizen Scientist” is best understood as an honorary title for anyone who voluntarily participates in any level of the scientific enterprise, even if most participants primarily engage in data collection [3].

Scientific interest in biodiversity has surged in recent decades [4,39]. However, tracking and mitigating biodiversity loss requires fine-grained data across regional to continental scales and over extended time frames, an undertaking that is resource-intensive for professional scientists and managers [6,7]. Consequently, researchers and policymakers advocate citizen science as a strategic solution to address large-scale data gaps [4,6]. By mobilising public participation, citizen science initiatives can significantly enhance both basic and applied research.

In countries like United Kingdom, USA, France, Germany, Australia and China, citizen science has evolved rapidly, with numerous biodiversity monitoring programs [8-10]. This current growth is closely linked to rising awareness of the critical role of Insect Pollinators (IPs), whose decline threatens agricultural productivity [11,12].

Literature indicates that approximately 87% of angiosperm species rely on animal pollination [12], underscoring the urgency of monitoring pollinator populations amid pressures from urbanization, agricultural intensification, pesticide use, and climate change [11]. Despite these global trends, citizen science in pollinator monitoring remains underutilised in most SSA countries, especially Zambia with only a few isolated studies reported, and many of these studies do not focus on IPs.

The limited adoption of citizen science in Zambia, despite its demonstrated value elsewhere, poses a significant challenge. This gap constrains the country’s ability to monitor and conserve its rich biodiversity and to address critical environmental issues such as pollinator decline. The underutilization of citizen science in Zambia, compared to its growing global application and in other SSA countries, like South Africa highlights the need to investigate barriers to its adoption and identify pathways for scaling up. This study therefore seeks to answer three key questions:

a) What is the potential of citizen science in Zambia for biodiversity monitoring and conservation?

b) What specific challenges impede the adoption and implementation of citizen science initiatives in Zambia?

c) What opportunities exist for scaling up citizen science in Zambia to effectively monitor biodiversity and address pressing environmental issues?

2. What is Citizen Science?

Citizen science encompasses contributory models (publics collect data under expert protocols), collaborative models (participants may also analyze), and co-created projects (participants help define questions and methods) [8,3,1]. These models are scaffolded by open science infrastructures and digital tools that ease observation, submission, feedback, and reuse of data. Contemporary definitions increasingly stress co-production of knowledge, reciprocity, and inclusion, especially when projects are designed from the outset with educational and community outcomes [5,7].

3. The Potential Benefits of Cs in in Zambia and Africa

Historically, the use of CS is well established within the fields of sustainable natural resource monitoring and biodiversity conservation, where it has been instrumental in generating large-scale ecological datasets and informing management decisions [13,14,42]. Citizen science offers an attractive paradigm for addressing some of the complex socio-environmental challenges facing society, particularly in data-scarce regions such as Sub-Saharan Africa (SSA) [15,16,44]. The primary benefits of CS relative to traditional science reflect a complex balance of cost, data quality and quantity, and the speed at which scientific outcomes are disseminated [2,17,41].

Cost-effectiveness is a key consideration, especially given the high costs associated with traditional scientific approaches coupled with reductions in research funding. Citizen science is generally more cost-effective because it leverages the unpaid or low-cost contributions of volunteers, reducing labour expenses while enabling large-scale data collection [4,17,18]. Some reports indicate that the United States alone generated an in-kind value of approximately US $2.5 billion annually from biodiversity-related CS projects (though this figure is likely an underestimate since only 12% of projects reported volunteer contributions) [4,40]. Similar cost-saving potential exists in SSA countries, where CS can help fill critical data gaps in environmental and biodiversity monitoring [16,19].

Away from the economic benefits, educational and engagement outcomes are central to the value proposition of CS. The involvement of citizens in scientific processes, CS promotes public understanding of science, promotes environmental literacy, and enhances trust in scientific institutions [2,45]. The participants in CS projects often gain knowledge and skills that empower them to make informed decisions about sustainability and resource management [20]. This two-way exchange of knowledge transforms CS from a mere data collection exercise into a participatory learning experience, creating informed citizens who can act sustainably and advocate for evidence-based policies [2].

In addition, CS delivers social benefits, such as capacity building, community empowerment, and the democratisation of science [21,22]. By giving individuals a voice in research and decision-making, CS can strengthen social cohesion, foster inclusivity, and promote equity in knowledge production [23]. Like other SSA countries, Zambia's marginalised communities often lack representation in scientific discourse, CS initiatives can bridge gaps between local knowledge and formal science, contributing to more just and context-sensitive solutions [24].

Finally, CS presents opportunities to support policy and governance objectives by generating locally relevant data that can inform national and regional strategies for achieving Sustainable Development Goals (SDGs), especially focusing on biodiversity conservation, climate resilience, sustainable livelihoods and poverty reduction [16,25]. The integration of citizen-generated data into official statistics remains a challenge in SSA countries, but successful examples within Africa and at the global level demonstrate its potential to enhance evidence-based decision-making in resource-constrained settings [17].

4. Challenges Impeding the Adoption of Cs in Sub-Sahara Africa

Despite its promise, the adoption of CS in Zambia and many other SSA countries faces multiple barriers that hinder its scalability and effectiveness. These challenges are rooted in low awareness levels, technological limitations, socio-economic conditions, cultural diversity, and institutional weaknesses.

4.1. Lack of Awareness and Understanding

One of the most significant barriers is the limited awareness of CS among the public, policymakers, and even some scientific communities. Many people in Zambia are unfamiliar with the concept of CS, its benefits, and its role in scientific research [22,26]. This lack of understanding reduces public participation and limits institutional support, as CS is often perceived as informal or lacking scientific rigor. This challenge is particularly pronounced, where CS initiatives remain largely unknown outside academic circles, as is the case in the country.

The absence of awareness campaigns and educational programs exacerbates this issue. Without targeted outreach, CS remains confined to small, isolated projects in some countries rather than becoming a mainstream approach to data collection and environmental monitoring in SSA. Furthermore, policymakers' limited understanding of CS means that it is rarely integrated into national research agendas or development strategies, reducing its potential to influence policy and decision-making [27].

4.2. Limited Technological Infrastructure and Digital Access

The transition from traditional paper-based research to mobile and digital platforms is ongoing but uneven across among research communities in Zambia [15]. Like in many SSA countries, Zambia lack reliable internet connectivity, electricity, and affordable mobile data, which are essential for digital CS platforms [24,15]. While mobile phone penetration is increasing, the cost of smartphones and data remains prohibitive for many CS potential participants. This digital divide restricts participation to university researchers and students, undermining the inclusivity of CS projects.

Moreover, even where infrastructure exists, technical literacy remains a challenge. Many citizens lack the skills to use mobile applications or online platforms effectively, limiting their ability to contribute data or engage with scientific content. This creates a dependency on intermediaries, such as NGOs or local facilitators, which can increase project costs and reduce scalability [24].

4.3. Socio-Economic Barriers

The rates of poverty and literacy in Zambia, especially in peri-urban and rural communities are high (estimated at 78.8%) [28]. High poverty levels and low literacy rates significantly constrain participation in CS projects. For example, limited education affects the ability to acquire technical skills, while economic hardship restricts access to smartphones and other digital tools [24]. These socio-economic disparities create an uneven playing field, where only relatively affluent populations can engage meaningfully. Furthermore, gender disparities in education and technology access exacerbate these challenges in Zambia [29,30]. For individuals struggling to meet basic needs, volunteering time for CS activities may not be feasible. Without financial incentives or tangible benefits, participation rates remain low, especially in resource-poor settings. This will and may limit the representativeness of CS data and undermines its potential to inform inclusive policies [22].

4.4. Institutional and Policy Barriers

The integration of CS into policy and decision-making processes in SSA countries, especially Zambia remains limited. In Zambia there are no clear frameworks for incorporating citizen-generated data into environmental monitoring systems [22,27]. Weak institutional capacity, fragmented governance structures, and limited funding further hinder the development of open science ecosystems that could support CS. Without formal recognition and policy backing, CS projects struggle to achieve long-term sustainability and impact.

Additionally, the absence of standardised protocols for data validation and quality assurance creates scepticism among policymakers and scientists regarding the reliability of CS data. This lack of trust prevents CS from being fully utilised in evidence-based decision-making, reducing its potential to influence environmental governance and sustainable development strategies [26].

4.5. Cultural and linguistic Diversity

The other anticipated challenge is the linguistic diversity in the country. The numerous local/indigenous languages [31], poses a significant challenge for CS projects that rely on standardised data collection protocols [27]. Many CS platforms and training materials are available only in global languages, excluding large segments of the population who speak local languages. This language barrier reduces participation and limits the inclusivity of CS initiatives.

Cultural perceptions of science and technology can also influence participation. In some communities, scientific engagement is viewed as irrelevant or inaccessible, particularly when projects fail to align with local priorities or knowledge systems [24]. Overcoming these barriers requires culturally sensitive approaches that respect local traditions and integrate indigenous knowledge into CS frameworks.

4.6. Data Governance and Trust Issues

Concerns about data ownership, privacy, and benefit-sharing often discourage participation, especially among marginalised and Indigenous communities [24]. Without clear ethical guidelines and transparent governance, CS projects risk reinforcing existing power imbalances rather than democratising science. Participants may fear exploitation or misuse of their contributions, leading to reluctance in sharing data.

Building trust requires participatory design processes that involve communities in decision-making about data use and benefit distribution. Establishing clear agreements on intellectual property rights, data access, and attribution can help address these concerns. Without such measures, CS initiatives risk perpetuating extractive practices that undermine their legitimacy and sustainability [32].

5. Opportunities for Scaling up Cs in Sub-Sahara Africa

Despite the challenges facing CS in Zambia, and SSA countries in general, several opportunities exist to scale up its adoption and impact. These opportunities leverage technological advancements, institutional partnerships, capacity-building initiatives, and policy integration to create a more inclusive and sustainable CS ecosystem.

5.1. Leveraging Mobile Technology and Digital Platforms

The rapid expansion of mobile technology in SSA countries presents a transformative opportunity for scaling CS. Mobile penetration in the region continues to grow, with 4G adoption projected to reach 50% by 2030 and early 5G deployments already underway [33]. These advancements enable real-time data collection, georeferenced observations, and multimedia submissions, which are critical for biodiversity monitoring, agricultural research, and environmental management. Mobile applications such as iNaturalist and Open Data Kit have already demonstrated their potential in facilitating large-scale citizen participation in ecological monitoring [47,48].

However, leveraging ICT for CS requires more than just connectivity. Project designs must address the persistent usage gap, which affects 60% of people living within network coverage but unable to access mobile internet due to affordability and digital literacy barriers [33,34]. Solutions include offline data capture, zero-rated data partnerships, and local language interfaces to ensure inclusivity. ICT-driven CS initiatives should not merely impose technology but integrate participatory design principles that align with local contexts [35]. When combined with the inherent strengths of CS, longitudinal data collection and large observer networks, digital platforms can significantly enhance data quality and availability for ecological and agricultural research.

5.2. Building Partnerships with Stakeholders

Strategic partnerships are essential for scaling CS initiatives in Zambia, and the SSA. For instance, collaborating with local NGOs, community-based organisations, and government agencies ensures that CS projects are contextually relevant and aligned with national priorities. Such partnerships can facilitate resource mobilization, enhance trust among communities, and provide institutional support for integrating citizen-generated data into official statistics and policy frameworks [36,43]. For example, the Citizen Science for Conservation in Africa (CISCA) established in 2018, is an initiative used successfully to train practitioners from nine African countries to design robust CS protocols and translate data into conservation action [37].

Within the SSA countries, some government agencies, such as the South African National Biodiversity Institute (SANBI), have demonstrated how public institutions can mainstream CS into national biodiversity assessments and citizen-driven campaigns like the City Nature Challenge with 2,960 observers, documenting 9,551 species from 10 African cities [37,38]. These collaborations not only strengthen data governance but also create opportunities for sustained funding through national budgets and international donors. [36], creating a cadre of trained CS professionals who can mentor others and scale best practices across the continent [27].

6. Practical Recommendations for Scaling CS in SSA

As demonstrated in the preceding paragraphs, scaling CS in Zambia requires a multi-pronged approach that addresses technological, institutional, socio-economic, and governance challenges. This study recommends the following actions.

6.1. Strengthen Digital Infrastructure and Accessibility

Improving digital infrastructure is fundamental to scaling CS in Zambia. While mobile penetration is increasing, significant gaps remain in rural connectivity, affordability, and digital literacy [34]. Governments, telecom operators, and development partners should prioritize investments in affordable broadband, community Wireless Fidelity (Wi-Fi), and rural network expansion. These efforts will ensure that CS platforms can reach underserved populations, enabling inclusive participation in data collection and environmental monitoring [34].

Beyond connectivity, CS platforms must be designed for inclusivity. This includes features such as offline data capture, zero-rated data partnerships, and local language interfaces to overcome barriers related to cost and linguistic diversity. Digital literacy campaigns should accompany these technological interventions to build confidence among participants in using mobile applications for data collection and reporting. Without these measures, the digital divide will continue to limit the scalability and representativeness of CS initiatives.

6.2. Institutionalize CS in Policy Frameworks

For CS to achieve long-term sustainability and impact, it must be embedded within national science and environmental policies. This urges that governments to formally recognize CS as a complementary data source for monitoring biodiversity, climate change, and Sustainable Development Goals (SDGs) [25,46]. This recognition should be accompanied by the development of data validation protocols and interoperability standards to enhance trust in citizen-generated data among policymakers and scientists.

Institutionalisation also requires dedicated funding mechanisms. While international donors can provide catalytic funding for pilot programs and capacity-building initiatives, national research budgets should allocate resources for CS projects. By integrating CS into official monitoring systems and policy frameworks, governments can leverage its potential to generate high-resolution, locally relevant data that informs evidence-based decision-making.

6.3. Develop Capacity-Building and Training Programs

Capacity building is a cornerstone for scaling CS in SSA. Many potential participants lack the technical skills required for data collection, analysis, and interpretation. Targeted training programs can bridge this gap by equipping volunteers, local leaders, and practitioners with the necessary competencies. Initiatives like CISCA have demonstrated the effectiveness of structured workshops in training CS managers to analyse data using tools such as R, interpret long-term trends, and communicate findings to policymakers [37].

Beyond technical skills, capacity-building efforts should focus on digital literacy, data ethics, and advocacy skills. This holistic approach empowers communities to not only collect data but also use it for local decision-making and policy influence. Regional hubs and networks can institutionalize these programs, creating a cadre of trained CS professionals who can mentor others and scale best practices across the continent [27].

6.4. Promote Data Ethics and Governance

Trust is a critical enabler of CS participation. Concerns about data ownership, privacy, and benefit-sharing often discourage participation, especially among marginalised and Indigenous communities [24]. Establishing clear ethical guidelines and transparent governance frameworks is essential to address these concerns. These frameworks should define data ownership rights, outline benefit-sharing mechanisms, and ensure that participants are acknowledged for their contributions.

Participatory governance models can further enhance trust by involving communities in decisions about data use and dissemination. This approach not only promotes equity but also strengthens the legitimacy of CS initiatives. Without such measures, CS risks perpetuating extractive practices that undermine its democratising potential.

7. Conceptual Framework for Scaling Citizen Science in SSA

This study proposes a conceptual framework for scaling CS in Zambia and is built on four interconnected pillars, such as Technology Enablement, Capacity and Community Engagement, Governance and Trust, and Institutional integration.

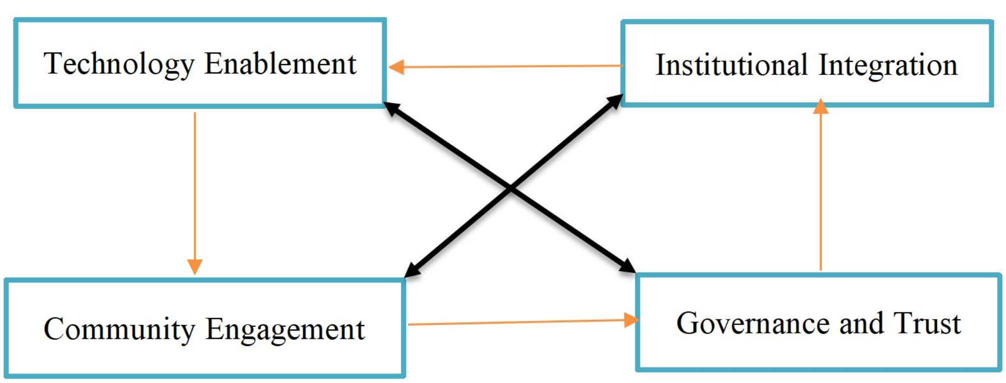

Figure 1: Conceptual framework illustrating the four interconnected pillars for scaling citizen science in Zambia.

This framework conceptualizes the interlinked components necessary for the successful scaling of citizen science initiatives in Zambia. Technology enablement provides the digital infrastructure for participation, while Institutional Integration ensures policy alignment and data legitimacy. Capacity and Community Engagement empower citizens through training and inclusion, and Governance and Trust safeguards ethical practices and data integrity. These pillars are mutually reinforcing, forming a feedback loop that enhances data quality, community ownership, and policy relevance.

8. Future Directions

Future research should focus on developing targeted interventions that specifically tackle the challenges identified in this study. There is a growing need to specifically come up with ways to raise public awareness through organised outreach and education programs. Stakeholders should work on fixing gaps in digital infrastructure by testing technologies that are accessible to everyone, like mobile apps that work offline and interfaces in local languages. Researchers and institutions should focus on find ways to get more people involved by considering incentive models and community-based engagement approaches that help close the gaps between men and women and between people of different social and economic backgrounds. These efforts will make CS projects in Zambia and more open to everyone, long-lasting, and useful.

9. Conclusion and Recommendations

Citizen science presents a practical and impactful approach to enhancing biodiversity monitoring and conservation in Sub-Saharan Africa, particularly Zambia. By leveraging mobile technology, fostering institutional support, and engaging communities through capacity-building, Zambia can close critical data gaps and empower local stakeholders. To scale these efforts, it is essential to invest in inclusive digital infrastructure, integrate citizen science into national policy frameworks, and promote ethical data governance. Strategic partnerships and targeted training programs will further ensure sustainability and relevance. With modest investments and coordinated action, CS can become a cornerstone of Zambia’s environmental and biodiversity conservation strategy.

Author Contributions

Dr. Christopher Mulwanda led the research, drafted the manuscript, and coordinated revisions.
Maggie Mapalo Mwape and Mainess Kandah Namuchile played a significant role in conceptualising the manuscript and editing.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of this paper.

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