TECHNICAL BRIEF

The role of citizen science in improving ambient water quality

Sustainable Development Goal Target 6.3

Prepared by the World Water Quality Alliance – 'Citizen Science for SDG indicator 6.3.2' workstream

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Disclaimer

Acronyms:

BMWP	Biological Monitoring Working Party (UK)
CaSTCo	Catchment Systems Thinking Cooperative (UK)
EA	English Environment Agency
FAIR	Findable, Accessible, Interoperable, and Reuseable
GBIF	Global Biodiversity Information Facility
GDP	Gross Domestic Product
GEMS	Global Environment Monitoring System
NGO	Non-Governmental Organisation
NRW	National Resources Wales
NSO	National Statistics Offices
NWRMA	National Water Resource Management Agency
QA/QC	Quality Assurance/ Quality Control
RMI	Riverfly Monitoring Initiative (UK)
SASS	South African Scoring System
SDG	Sustainable Development Goal
SEPA	Scottish Environmental Protection Agency
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
WRA	Water Resources Authority of Kenya
WRUA	Water Resource User Association (Kenya)
WUA	Water User Association (Tanzania)
WWQA	World Water Quality Alliance

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About the World Water Quality Alliance

The United Nations Environment Assembly (UNEA) Resolution 3/10 on "Addressing water pollution to protect and restore water-related ecosystems" (UNEP/EA.3/Res.10) requested that UNEP develop a global water quality assessment in collaboration with UN-Water and relevant stakeholders by UNEA-5. During the inception meeting for the assessment, around 50 organisations (UN, research, civil society, private sector) who had expressed interest to engage in the assessment, also expressed interest in working with UNEP to co-design agendas and action around emerging issues. This group formed the World Water Quality Alliance (WWQA), an open, global consortium, pooling expertise on water quality science and technology innovation. Together, they address priority topics relevant to water governance, scalable water solutions and emerging issues in water management serving countries throughout the lifetime of the 2030 Agenda for Sustainable Development and beyond. **UNEP's Global Environment Monitoring Systems for Early Warning for Environment Unit** hosts the WWQA Coordination Team. At the time of writing, the WWQA comprised 16 Workstreams with guidance from a Strategic Advisory Committee and a Technical Advisory Committee. Through these Workstreams, the WWQA provides policy-relevant focus for change, advocating the central role of freshwater quality in achieving prosperity and sustainability, delivering evidence and raising awareness on key topics.

The WWQA Citizen Science for SDG indicator 6.3.2 Workstream, led by Earthwatch Europe in partnership with UNEP GEMS/ Water, comprises an active working group of specialists and practitioners, and is actively testing the feasibility of combining citizen data with regulatory data for SDG indicator 6.3.2 reporting in several countries.

WWQA
World Water Quality Alliance

Executive Summary

There is an increasing international recognition of the need to address the challenges around water quality at a global scale. In 2023, the UN Water Conference made clear that water is essential for the achievement of the Sustainable Development Goals (SDGs), and for the health and prosperity of people and planet. However, the progress toward meeting key water related targets remain dangerously off track. The 2024 United Nations Environment Assembly (UNEA 6) resolution on Effective and inclusive solutions for strengthening water policies (UNEP/EA.6/Res.13) makes clear that the collection of water quality data needs to be enhanced and used for evidence-based water resource management. Despite awareness that good ambient water quality in rivers, lakes and aquifers is crucial for human survival, it is alarming how little information about the quality of water is available. Urgent action needs to be taken to understand and consequently to protect our water resources.

The authors of this technical brief form the World Water Quality Alliance's (WWQA's) 'Citizen Science for SDG indicator 6.3.2' workstream, composed of water quality and citizen science experts from academia, national authorities, NGOs, and citizen science project coordinators. This brief reflects our collective recognition that, due to current limitations in water quality monitoring, **our 2030 target for ambient water quality (Target 6.3) will not be met without the use of citizen science.**

Citizen science is a wide-ranging term that refers to the involvement of non-professional scientists in scientific work. Citizen science data are widely used in global and local biodiversity monitoring and already directly contribute towards Sustainable Development Goals 14 (Life Below Water) and 15 (Life on Land). Its participatory nature means that citizen science also addresses multiple other SDGs, including, but not limited to, Goal 3 (good health and well-being), Goal 4 (quality education), Goal 5 (gender equality), Goal 16 (peace and justice strong institutions), and Goal 17 (partnerships to achieve the goals) (Fritz et al., 2019). Studies of the current citizen science landscape reveal that Goal 6 (clean water and sanitation) has particularly high potential for contributions from citizen science (Fritz et al., 2019). Two targets are of interest:

- Target 6.3: Improve water quality, wastewater treatment and safe reuse.
Indicator 6.3.2 focuses on the proportion of bodies of water with good ambient water quality. Professionally collected data for this indicator are limited by a shortage of funding and infrastructure. However, appropriate citizen science monitoring methods already exist and are producing reliable data, often as part of projects run by third parties (e.g., environmental non-

Testing for turbidity using a Secchi tube, Lower Kafue. Credit: WWF Zambia

governmental organisations) (Quinlivan et al., 2020).

- Target 6b: Support and strengthen the participation of local communities in improving water management. Public participation in freshwater monitoring helps to build local capacity in water management. It does this by increasing public literacy about water management issues, engaging hard-to-reach groups including women, youth, and marginalised communities, and providing clear, well-defined, and measurable mechanisms for participation and local co-management (Buytaert et al., 2016).

Despite the benefits of citizen science for monitoring indicator 6.3.2, uptake has been limited. National Statistics Offices (NSOs) and national authority water resource management agencies face obstacles including limited access to the data, scepticism about data quality, lack of understanding about the data collection methods, appropriate design and implementation of citizen science initiatives (Proden et al., 2022). Similarly, communities and citizen science project coordinators lack knowledge about the SDGs and how to interface effectively with them (Ballerini & Bergh, 2021; Warner et al., 2024).

In this technical brief, we show a number of cases where citizen scientist data have been successfully integrated with national monitoring data for SDG indicator 6.3.2 reporting and improved water management. From these experiences, we define three preconditions that must be met for national authorities to integrate citizen science data into their reporting for this indicator:

1. Data can be produced that meets the requirements of SDG indicator 6.3.2.

2. Citizen science participants are willing and able to collect the data.

3. There is an enabling framework that allows both the participants and the data they

produce to be incorporated into integrated water resource management.

Our experience suggests that integration of citizen science and national authority monitoring requires deliberate action. We urge national authorities to work with citizen science project coordinators and community organisations to do the following:

1. Nominate a focal point within your institution to explore the potential of citizen science for water resource management.
2. Task them with:
   a. Finding out which action pathway is best suited to your situation.
   b. Appraising your national monitoring capacity as reported through indicator 6.3.2 (available on the **SDG Water Quality Hub**)
   c. Exploring which citizen science programmes have the most potential for your national context and establishing collaborations where appropriate (examples are available in chapter 2 of this document)
3. Consider the resources needed for implementation, including scientific design, strategies to promote engagement and collaboration with volunteers, and the overall framework that allows national authorities and citizen scientists to share data and work together.

We provide a checklist of the most important practical questions that should be asked by NSOs and national authorities, whether they wish to harness existing citizen science projects or establish new ones. We then detail how each of these questions might be approached. Based on these considerations, we propose a priority matrix of actions that can be taken by NSOs and national authorities to accelerate data gathering for indicator 6.3.2 using citizen science while simultaneously strengthening community participation in water resource management.

Credit: Ash Seddon, Unsplash

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Credit: Ground Truth and DUCT

The Challenge of Ambient Water Quality Monitoring

Sustainable Development Goal 6 calls for all United Nations member states to ensure availability and sustainable management of water and sanitation for all by 2030. Meeting this goal requires facing various challenges that are causing freshwater ecosystem loss and rapid degradation of the natural water resources that remain. This is recognised within the SDG framework by Target 6.3: *"to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally"* (A/RES/70/1.).

Robust and – crucially – relevant monitoring at a large scale is essential to understand what the current state of our water is, what management interventions should be designed and implemented, and whether those interventions are effective. Given that such interventions often require cross-sectoral and transboundary cooperation, it is also vital that data and information from and for many different stakeholders served by water resources are embedded in integrated water management and policy.

With just six years left to meet Target 6.3, one of the biggest challenges we face is gathering enough good quality information to understand what the true current state of our ambient waters is and what needs to be done to improve the status of water bodies (UNEP, 2021).

Analysing *how* countries report on SDG indicator 6.3.2 provides good insight into the significance of this data gap. Indicator 6.3.2 provides information on the capacity of countries to monitor and assess the quality of their rivers, lakes and aquifers. It is clear that many countries struggle to collect sufficient data. In high-income countries, worsening water quality issues and climate change are placing increasing pressure on water treatment, yet monitoring in some locations is inconsistent or requires improvement. Low-income countries show particularly poor data reporting: of 77,000 water bodies reported on in 2020, only 1,300 were from the 22 lowest income countries (UNEP, 2021) (Fig. 1). This paucity of data from low-income country contexts is especially alarming, considering that communities in low-income regions are most likely to be at risk, using water directly from ambient sources without any treatment.

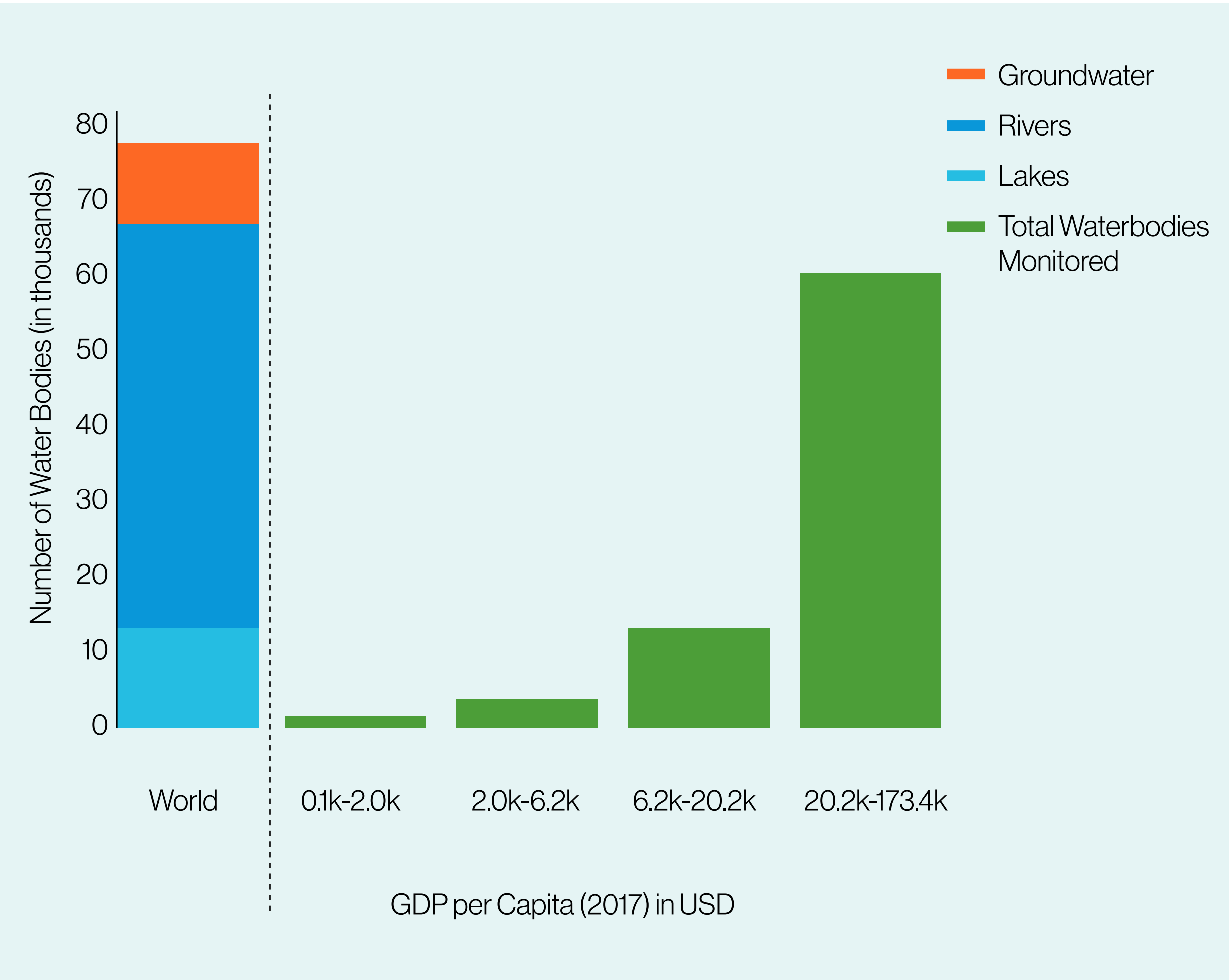

Figure 1. Number of water bodies that were reported on in 2020 for SDG indicator 6.3.2, globally and per GDP per capita quartile group.

To understand the gap in water resource monitoring data, it is useful to compare the number of water bodies globally against the number that have been reported on for this SDG indicator. Defining the number of rivers and aquifers globally is challenging because methods of delineation contrast between countries. However, there are good estimates of the quantity of lakes. HydroLAKES (Messager et al., 2016) includes a dataset of 1.4 million lakes over 10 hectares in surface area. Analysing how many of these lakes are included in the SDG reporting information provides a clear picture.

Table 1 shows the total number of lakes per SDG region, the total number of lakes in countries that reported on this SDG indicator; and the number of lakes that those countries reported on. The last column shows the proportion of lakes reported on in reporting countries. There are regional differences, but globally this table illustrates that despite good information on the number and distribution of lakes, there is very little available on lake water quality. In fact, the number of lakes that are reported on is less than one per cent of the global total. Furthermore, although we do not have a similar measure for rivers and groundwaters, evidence suggests it is equally bleak (UNEP, 2021).

SDG Region	Total lake count	Lake count in reporting countries	Lake count reported on in 2020	Percentage lakes reported on
Australia and New Zealand	12,021	12,021	57	0.47%
Central and Southern Asia	28,514	12,484	31	0.25%
Eastern and South-Eastern Asia	37,151	3,716	72	1.94%
Europe and North America	1,267,264	1,257,546	11,281	0.90%
Latin America and the Caribbean	59,987	48,245	999	2.07%
Northern Africa and Western Asia	2,502	427	13	3.04%
Oceania	1,030	17	3	17.65%
Sub-Saharan Africa	15,189	12,947	366	2.83%

Table 1. Number of lakes and the number included in SDG indicator 6.3.2 reporting in 2020 per SDG Region

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Credit: *Ground Truth and DUCT*

Citizen Science as a Solution

Citizen science (Fig. 2) is now being widely recommended as an effective means of co-monitoring and co-managing water systems, as well as filling country- or community-level gaps in SDG monitoring data (Fritz et al., 2019; Metcalfe et al., 2022). Citizen science is already widely used in natural resource management outside of the water sector, particularly for monitoring and conserving biodiversity (Chandler et al., 2017). In addition to data provision, citizen science is also providing opportunities for public engagement and education, incorporating and engaging local knowledge, increasing support for decision making processes, co-creating solutions to water quality issues, and promoting inclusion and more just access to science.

Definitions
Citizen science means different things to different people

- The **involvement of the public** in any stage of the scientific process [15]
- A form of **stakeholder engagement** and a way to address societal challenges [1]
- **Democratisation** of science and policy [16]
- A method to improve **inclusiveness and justice** [17]

Features
Citizen science can assist water monitoring and management because:

- Participants can collect data with a **greater spatial and temporal extent** than professional monitoring alone, including remote and hard-to-reach areas
- The process of doing citizen science has **wide-ranging social benefits** from education to inclusion of marginalised groups
- Participant involvement can help ensure data is **relevant to localised decision-making**
- Data is FAIR (**findable, accessible, interoperable, and reusable**) and therefore readily available for use

Project goals
Citizen science can be used for:

- **Action:** A tool to support participant intervention in civic agendas
- **Conservation:** Local stewardship and involvement in natural resource management
- **Investigation:** Focused on collecting data for scientific research goals and hypotheses
- **Virtual:** Entirely online activities, usually data processing (e.g. image classification)
- **Education:** A tool for outreach and providing learning opportunities

Features
Relationships between participants and professionals can be:

- **Contractual:** Communities ask professional researchers to conduct research on their behalf
- **Contributory:** Professional researchers design the project and participants contribute by collecting data
- **Collaborative:** Professional researchers lead the design of the project with input from participants
- **Co-created:** Professional researchers work together throughout the research process
- **Collegial:** Research is conducted independently by participants themselves

Figure 2. Characterisations of citizen science

Many citizen science projects have been identified that aid in monitoring and managing both surface and groundwater. Outcomes of such projects include increased availability of higher spatial and temporal resolution of data (including data on the chemical and biological parameters listed in SDG indicator 6.3.2), greater participation of local people in water resource monitoring and management, and raised public education and awareness concerning water-related issues (Goldin et al., 2023; Kirschke et al., 2022). Therefore, there is clearly huge potential for citizen science to be applied directly to monitor ambient water quality (SDG indicator 6.3.2) while simultaneously increasing the participation of local communities in water resource management (SDG target 6b).

Examples of citizen science projects

There are already many examples of citizen science projects around the world that can be directly scaled up or used to inform widespread adoption of the approach.

Example 1: Chemical monitoring of water quality

There are several citizen science projects that support direct monitoring of water quality parameters. FreshWater Watch (www.freshwaterwatch.org) is a global project established in 2012 to help local communities record phosphates, nitrates, turbidity and visual observations using simple, low-cost chemical kits. There have been 41,000 water quality observations made to date from over 35 countries worldwide. All volunteers belong to a local 'group', allowing data collection strategies to be tailored to specific contexts. Scientific support is provided and data are uploaded to a global database via a web or mobile phone app. The full dataset is open access and available for anyone to download. There are numerous strategies in place to ensure the quality of the data. For instance, all volunteers must undergo training before they are able to collect the data. Moreover, the kits have been tested against lab protocols (Quinlivan et al., 2019), and data are checked for errors both by local group coordinators and by the FreshWater Watch project team.

The Water Rangers initiative (www.waterrangers.ca) was originally founded in Canada in 2015 but is now expanding to Europe. Volunteers can purchase kits to test for a variety of different parameters including phosphate, nitrate, pH, salinity, and conductivity. There is an open data platform for displaying results, with resources and information made available to support volunteers.

Several water quality projects contribute, or are planning to contribute, to SDG indicator 6.3.2 reporting at a country level, though this is currently limited to a small number of waterbodies. Examples of how national authorities are working with volunteers using FreshWater Watch can be found in section 5.

Example 2: Biomonitoring

Another common citizen science approach is to use river invertebrates as an indicator of water quality. The mini stream assessment scoring system (miniSASS; https://minisass.org/) was developed in South Africa based on the professional South African Scoring System (SASS) version 5 and is now expanding across Southern Africa and globally (Graham et al., 2004)]. Volunteers survey streams or rivers for aquatic macroinvertebrates that fall into 13 easily-identifiable groups, from which they derive a river health score that helps them to understand water quality and river ecosystem

Biomonitoring, South Africa. Credit: Ground Truth health. Data are uploaded onto Google Earth via the website, and a mobile app provides miniSASS operators with a platform to help learn about miniSASS and how to conduct a survey, identify aquatic macroinvertebrates sampled, and capture and submit data (including various anecdotal data such as water clarity as measured by a clarity tube, water temperature, site photographs, or qualitative data such as descriptions of sites) off- or online while in-field. The miniSASS scores have been rigorously benchmarked against SASS5 and miniSASS records are verified by the organisation GroundTruth. The strengths of miniSASS include that it costs very little to implement, the results are available instantly, the methodology is very user-friendly, the assessment provides a more holistic picture of river health and water quality than any single chemical parameter, and it serves as a powerful tool for environmental engagement and education. MiniSASS scores have been used to generate SDG indicator 6.3.2 scores for 40 water bodies in South Africa (Taylor et al., 2021).

The Riverfly Monitoring Initiative (RMI) (www.riverflies.org) is a similar initiative widely used in the United Kingdom. Scores are based on the Biological Monitoring Working Party (BMWP) scoring system, widely used for professional water quality monitoring across Europe. RMI volunteers work directly with the Environment Agency (the UK's River Management authority) to set a 'trigger level' score for their site (Brooks et al., 2019). The Environment Agency is called to investigate possible pollution when any river health score drops below this trigger level. This framework allows volunteers to work closely with river management professionals to respond to incidents as they happen.

Example 3: Visual monitoring

In China, the "Black and Smelly Waters" app, run via WeChat, allows citizens to report visual indicators of water quality problems by firstly taking a photo, and then ranking the level of floating trash, odour, and water colour. The app is managed and owned by the national authority, which pledge to respond to submissions within seven working days. They use this information, sometimes combined with verification from third-party organisations, to determine problem locations and produce management plans. Research suggests that these visual reports can successfully help determine polluted vs non-polluted waterbodies when compared to chemical analysis (Hsu et al., 2020). This example demonstrates how national authority-led citizen science projects can contribute directly to water quality management by providing citizens a means to participate in environmental management as well as improving the civic transparency of existing processes.

Example 4: Combining existing tools for local benefit

While citizen science data can be shared globally, the benefits of citizen science are often felt at the local level. Diamonds on the Soles of our Feet is a citizen science project supported by the University of Western Cape, South Africa, monitoring river health in Limpopo. Within this project, data collection happens via a youth development programme. Youth from seven schools, each close to rivers to ensure easy access to the monitoring locations, collect data on phosphates and nitrates using FreshWater Watch, river health using miniSASS, and E. coli and coliforms using other citizen science tools. Citizen science activity is accompanied by an education programme aimed at making young learners aware of water quality concerns. WaterBlitz events – weekend events devoted to taking measurements – provide a trigger for participants to collect data.

This project illustrates the potential for citizen science to collect data for indicator 6.3.2 while simultaneously addressing several other SDGs, for example SDG 4 (quality education), SDG 10 (reduced inequalities), and SDG 17 (partnerships for the goals).

Similarly, the [Drinkable Rivers Citizen Science program] enables people to monitor the health of their rivers. Ultimately, it also helps to track progress towards their goal: a world with drinkable rivers, where they form a worldwide community of organisations and communities called hubs that monitor the water quality using the Drinkable Rivers measurement kit, manuals, instruction videos and a data platform to record, collect and share the data. They already have 60 citizen science hubs in 20 countries and are rapidly growing. These hubs are run by enthusiastic people who mobilise volunteers around them to join. Most hubs are part of local environmental organisations, schools, visitor centres or companies. Citizens are trained before they start taking measurements, and helped to form their own local measurement plan, applicable and suitable to their local situation. Hubs are also stimulated to form partnerships with local governments or to combine their datasets with formal datasets.

Validation of the data happens in numerous ways, and the measurement kit is developed with the input of many scientists and experts, also based on the SDG indicator 6.3.2 monitoring standards, and the European Water Framework Directive. All hubs use the same professional measurement kit and share their research data on the data platform. They collect 14 different measurements related to location, environmental health, chemical composition, physical aspects, ecological key-factors, visual factors and bacteria presence via E. coli measurements.

Example 5: Global Biodiversity Monitoring contributions to global indicators

This example does not relate directly to water quality monitoring but does demonstrate how citizen science data can be integrated into monitoring schemes and contribute to global indicators. Global Biodiversity Information Facility (GBIF) (www.gbif.org) contains nearly 1 billion biodiversity records, over half of which have been collected by citizen scientists. Major citizen science projects that contribute to GBIF include eBird, which collates bird sightings made by volunteers globally, and iNaturalist, which enables volunteers around the world to submit species recordings of any living thing.

Data from GBIF are used in several indicators within international framework agreements, including SDG indicators 15.1.2 (proportion of important sites covered by protected areas) and 15.4.1 (mountain biodiversity), as well as 15 of the 20 Convention on Biological Diversity Aichi Targets. Using these data, GBIF coordinate the Global Invasive Species Information Sharing Partnership using data collected by citizen scientists, and directly link citizen scientists to biodiversity-related policy and decision-making. It is clear from the example set by GBIF that citizen science can be scaled globally, and this could be replicated for water quality monitoring.

3

Monitoring Northwest Territories. Credit: Lindsay Day NWTCBM

Checklist for Monitoring Indicator 6.3.2 using Citizen Science

Monitoring ambient water quality using citizen science requires three basic preconditions to be met:

1. Data can be produced that meets the requirements of indicator 6.3.2.
2. Citizen science participants are willing and able to collect the data.
3. There is an enabling framework that allows both the participants and the data they produce to be incorporated into integrated water resource management.

Conventionally, data used for indicator 6.3.2 reporting are collected by or supervised by the national authority responsible for monitoring and managing the country's freshwaters. This is not the case for citizen science initiatives, which are commonly either run by, or involve, third parties. National authorities wishing to incorporate citizen science into their water monitoring and management regime can a) receive data from citizen science projects run by third parties, b) run their own citizen science projects, or c) a mixture of both. Achieving the three preconditions above requires cooperation between all stakeholders regardless of which approach is taken.

This section provides a checklist of practical questions (Fig. 3) to ask when assessing the potential for any citizen science project to contribute towards the monitoring and management of water resources. Taking each question in turn, the checklist outlines some of the considerations that National Statistical Offices (NSOs) and national authorities are likely to encounter when deciding whether citizen science will meet the three preconditions outlined above.

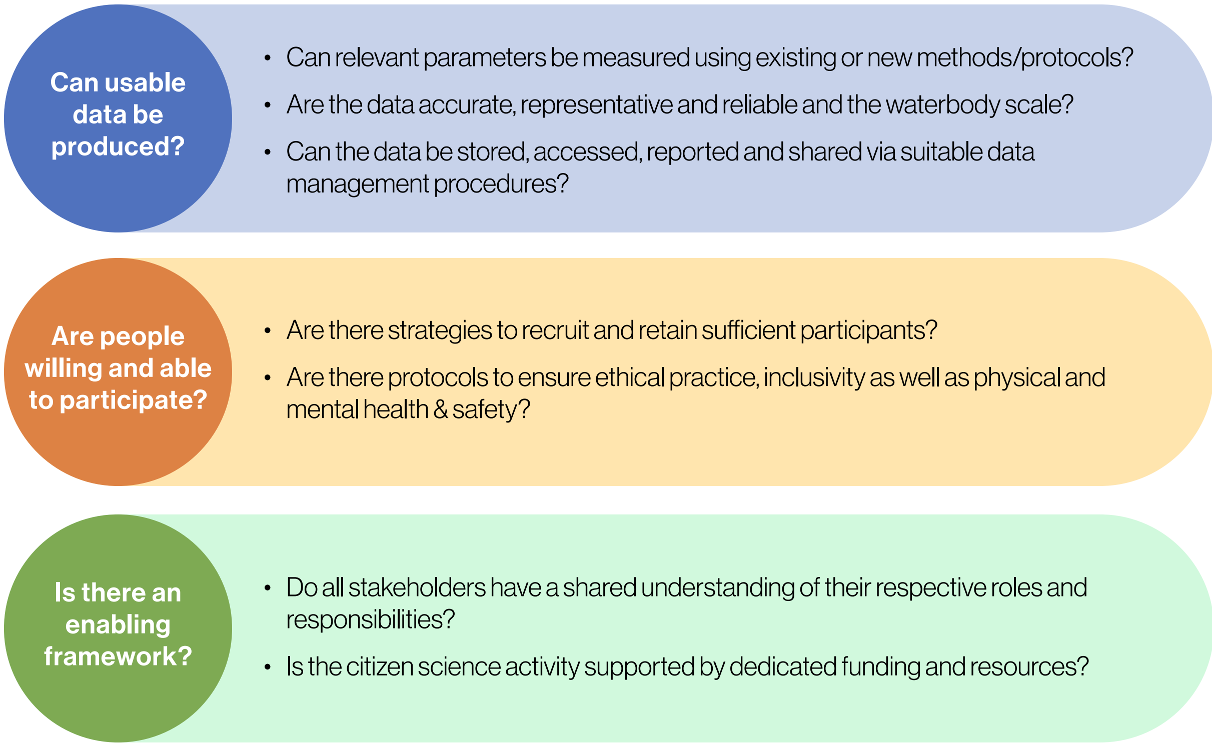

Figure 3. Checklist of requirements for using citizen science for monitoring indicator 6.3.2

1. Can usable data be produced?

Indicator 6.3.2 requires the identification of hydrologically relevant spatial units called 'water bodies'. Whether any given waterbody has 'good ambient water quality' is defined primarily by five core 'Level 1' water quality parameters (oxygen, salinity, nitrogen, phosphorus, and acidification). Additional 'Level 2' indicators can be used for countries to collect information that is of national relevance, for example related to specific local challenges. These data are compared to nationally defined standards to determine the condition of the waterbody. It is therefore important for member states to agree on the criteria that must be met by both existing and new citizen science projects whose data are to be used for reporting indicator 6.3.2.

Some important questions to ask include:

Can relevant parameters be measured using existing or new protocols/methods?

A great deal of progress has been made on the development of technologies, protocols and methodologies that are suitable for citizen science monitoring of ambient water quality for both surface water and groundwater (Nath & Kirschke, 2023; Ramírez et al., 2023). For both Level 1 and Level 2 parameters there is a well-established set of commercially available equipment at different price points, with different trade-offs in terms of accuracy, complexity, time resolution and cost. The Level 1 parameters Nitrogen (Nitrate, Nitrite, Ammonia, total N) and Phosphorus (orthophosphate, total P) can be sufficiently measured with simple tools, such as chemical test strips, that show results consistently comparable to professional methods (Nath & Kirschke, 2023) . In some instances, validation of the data may be necessary. Validation techniques for all parameters often require duplicate samples to be taken and analysed in laboratory conditions (with at least 20% of the number of samples checked as a rule of thumb). Therefore access to certified laboratories for testing (to which samples can be shipped and analysed usually within 48 hours) may be crucial for data validation. Level 2 parameters and the methodologies used to collect data for them are more varied. The use of simplified bio-indices (particularly for invertebrates) is common and offers opportunities to compare data directly to professional biological monitoring (Aceves-Bueno et al., 2017).

The choice of approach must consider not only the quality of the data produced, but also the skills, budget, time constraints, and personal preferences of the citizen scientists collecting the data. If citizen science data are to be used alongside professionally collected data, or if different groups will be collecting data using different methods, comparability between different approaches must also be considered. Decisions about protocols and methodologies can be made 'top down' (i.e., by the end user of the data), or they can be 'bottom up', whereby they are chosen in collaboration with project coordinators and/or participants.

Are the data accurate, representative, and reliable at waterbody scale?

One of the main concerns regarding the implementation of citizen science projects is the accuracy of the data produced by citizens. Research confirms that it is possible for citizens without a technical background to produce data that are comparable to data produced by a scientist - particularly after some initial training and with sustained engagement and feedback (Aceves-Bueno et al., 2017). This has been observed across a wide range of parameters though attention must be paid to the specific data quality requirements, particularly in terms of precision and accuracy and the implications for the selection of tools employed (Quinlivan et al., 2020). There are many different mechanisms for both quality assurance and quality control, and careful thought should be given to how these are deployed (Vohland et al., 2021) (Table 2). Documenting and communicating the accuracy and uncertainty associated with the data – including Quality Assurance/Quality Control (QA/QC) methods – is good practice and particularly important in situations where minimum acceptable standards are imposed.

Quality Assurance **Implemented before data are collected**	**Quality Control** **Implemented after data are collected**
Examples: • Training participants • Pre-testing and piloting data collection methods • Standardisation of protocols • Validation procedures within data collection and analysis protocols	Examples: • On-the-fly data correction and data cleansing • Retraining participants • Ongoing measuring and testing of data quality against professional standards

Table 2. Examples of data quality assurance and control mechanisms

It is important that data collected for indicator 6.3.2 are representative of the sampled waterbody. This means that the data or the sampling protocols must not be biased towards extremes of natural variability. An ideal monitoring strategy requires sustained regular effort, ideally at pre-defined intervals and representative locations. A well-designed citizen science project can increase both the number of locations monitored within a waterbody and the frequency of data collection, thereby increasing confidence that spatial and temporal variability is captured sufficiently (Bishop et al., 2020; Peeters et al., 2022). It can also provide highly tailored and population-specific characteristics that attend to the needs of local people (König et al., 2021). However, since citizen science projects are often designed for purposes beyond indicator 6.3.2, their respective sampling strategies arise from their intent and audience (Bishop et al., 2020). Even those designed specifically for monitoring indicator 6.3.2 must make compromises on sampling location and frequency based on the availability and locations of participants. When creating new projects, the sampling strategy should ideally be designed collaboratively between national authorities and participants. When combining data from citizen science projects with other types of monitoring, the sampling frequency and location of the combined datasets should be checked for compatibility with indicator 6.3.2 technical guidance.

Producing reliable data means that datasets are complete or have as few missing values as possible. For indicator 6.3.2 data need to be collected regularly over an extended period. This can be challenging for citizen science projects because they rely on the continued commitment and availability of participants, as well as continuity of funding and resources. Additionally, some citizen science projects are opportunistic by design – they encourage participation by allowing participants to collect data in an unstructured way, at any time and location that suits them (Callaghan et al., 2019). Missing data can occur because of short-term projects expiring (on average after a period of 1-5 years) (Quinlivan et al., 2019), and/or because of inconsistent volunteer effort. The likelihood of missing data can be minimised by providing appropriate support for volunteers on an ongoing basis. The impact of missing data can be accounted for using statistical techniques to assess any underlying biases if datasets are large enough to ensure statistical power (Gonsamo & D'Odorico, 2014).

Can data be stored, accessed, reported and shared via suitable data management procedures?

Well-designed citizen science projects should have appropriate data management strategies in place. They should aim to make their data and metadata findable, accessible, interoperable, and reusable (FAIR) (Wiggins et al., 2013). Similarly, countries wishing to incorporate citizen science data should ensure that they have appropriate data management protocols in place to keep track of the provenance of the data. Data management should be discussed with citizen science project coordinators where data from independently managed projects will be integrated into an indicator 6.3.2 monitoring strategy. Agreements on the types of metadata collected as well as common variables (e.g., sample grid references) might need to be made collectively between multiple projects and national authorities to facilitate combining datasets (Bowser et al., 2020).

One area of possible challenge for citizen science data management is in data transmission, as data gaps can be associated with remote areas in which internet and other telecommunication technologies are scarce or prohibitively expensive for participants (Weeser et al., 2018). Given that time and geographical stamping of data are crucial for analysis, projects need to consider the fit of the technologies employed with the sampling context. Furthermore, data storage, particularly if not possible through the cloud or other centralised services, needs to be planned before data collection begins. This may create limitations on the data that can be collected in remote areas.

2: Are people willing and able to participate?

Recruitment and retention of participants is vital for the success of any citizen science project. Participants initially engage – and then stay involved – in citizen science projects for a variety of reasons and participation can take different forms (Wehn & Almomani, 2019). Motivations for engagement are highly dynamic, culturally dependent and prone to change over time (Rotman et al., 2014). Understanding these motivations is key for ensuring participation – without participants the project will fail, so ensuring participant safety, satisfaction and enjoyment is vital. Where new citizen science projects are being designed for indicator 6.3.2 monitoring, they need to have sufficient resources to support participation. Where data from existing projects are being used, it can be beneficial to first assess the capacity of the project for maintaining effective participation and provide support and assistance where needed. Cooperation with existing initiatives might additionally facilitate direct connections with participants and local communities who are already motivated and involved in citizen science monitoring.

Some important questions to ask include:

Are there strategies to recruit and retain sufficient participants?

To participate in a citizen science project, an individual participant must have a) the physical and mental ability to participate, b) the motivation or desire to participate, and c) a trigger that causes them to act (Liñán et al., 2022). Barriers that reduce or prevent a participant from being able to take part can include practical barriers (e.g., inaccessibility of the physical locations in which the project takes place, time constraints, or a need to invest resources and funding) as well as psychosocial barriers (e.g., power imbalances, hierarchical structures, patronising approaches, and lack of trust of scientists in citizen science data) (Benyei et al., 2020). Participant motivations for taking part in citizen science can be extrinsic (e.g., learning/career development from data collection and project design, taking part in a social activity, fostering new networks or/and maintaining old networks, prestige in the community) or intrinsic (e.g., a desire to help, a sense of community) (Benyei et al., 2020). Triggers include hearing about a new or existing project, specific events or calls for participation, as well as internal personal triggers. Benefits and outcomes – individual and collective – should be clear and accessible, as they can encourage participants to engage in citizen science activities.

Participant retention requires transforming the initial act of participation into a repeated habit (Liñán et al., 2022). Participants are more likely to engage over longer periods where they are rewarded in ways that match their motivations, and when they become invested in the project process or outcomes (Gharesifard et al., 2019). Rewards are varied and can include networking and sharing results with researchers and other participants, material rewards (e.g., travel costs, equipment, monetary reward), awards and certifications, professional recognition, and public acknowledgement of contribution (Tweddle et al., 2012). The quality and level of support provided to participants throughout the project is a vital consideration.

Where new citizen science projects are created for monitoring indicator 6.3.2, a great deal of thought and planning should be given to strategies for recruiting and retaining participants (Table 3). Where citizen science projects already exist, the impact on participants of any additional demands or changes to the project that arise as a result of use of the data for indicator 6.3.2 must be carefully assessed, ideally in consultation with the participants and project coordinators.

Recruiting
• Broad advertising using social media or broadcasting • Targeted advertising using word of mouth • Joint meetings with potential participants to co-design projects and establish trust • Use of trusted intermediaries • Providing flexible participation methods • Providing incentives
Retaining
• Establishing a memorandum of understanding (MoU) between stakeholders and participants • Embed activity into existing structures, e.g., Youth Group activities • Regular two-way communication and feedback with participants • Acknowledgement of participant efforts

Table 3. Examples of strategies for participant recruitment and retention

Are there protocols to ensure ethical practice, physical and mental health and safety, and inclusivity?

Care has to be taken to guarantee ethical, health, and safety aspects, both physical and emotional, are met at all stages of a citizen science project. From an ethical perspective, participants should not be considered as simple data providers but as equal contributors to a joint of mission of advancing data collection, management, and use, as well as protection of water resources and addressing poor water quality. As such, participants should ideally be included in the design of monitoring activities and their feedback should be considered. Physical and emotional health and security issues must be given the outmost priority while designing and carrying out monitoring activities. To ensure this, specific trainings and tests to ensure physical safety are relevant for in-situ monitoring, where attributes such as confidence, hope and awareness should be nurtured for emotional security and sensitivity.

The potential of citizen science to increase public participation in water resource management is maximised when projects are designed to include different age groups, genders, and professional and socio-economic backgrounds. However, the specifics of who is involved and how depends on the actual goal of the project, the respective context, and the way of recruiting.

3: Is there an enabling framework?

Neither citizen science monitoring for indicator 6.3.2 nor public participation in integrated water resource management more broadly can be achieved unless they exist within a system that supports such activity. Conventionally, water quality monitoring is undertaken by or supervised by the parties responsible for decision making (national authorities). Citizen science initiatives are commonly either run by, or involve, third parties. These parties need to interface effectively with water resource management and its governance structures if the data are to be used. This means that national authorities wishing to monitor indicator 6.3.2 using citizen science must work alongside other stakeholders to create enabling structures and frameworks. In some cases, these frameworks may already wholly or partially exist, while in others they may need to be created.

Important questions to ask include:

Do all stakeholders have a shared understanding of their respective roles and responsibilities?

Citizen science projects can have a variety of different governance structures and corresponding levels of volunteer involvement. Two of the most common are a) contributory projects, which are usually run and managed by professional researchers who provide the infrastructure, expertise, and support needed for volunteers to collect data, and b) co-designed projects, where volunteers and professionals are equal parties in the design and management of the project (Goldin et al., 2022). Other formats include projects designed and run entirely by volunteers. There are pros and cons to each end of the top-down vs bottom-up spectrum. Top-down projects typically offer more control over project design, while bottom-up projects offer greater opportunity for participants to incorporate their own local knowledge, skills, and priorities into integrated water resource management strategies. Whatever structure is used, the roles and responsibilities of all parties must be agreed and transparent.

The roles of third-party stakeholders are equally important. Citizen science activities often involve academic institutions and non-governmental agencies and can also include the private sector, either as direct participants, data users, design consultants, or funders. In some cases, national authorities are themselves leading, contributing, or financing the activities (Hsu et al., 2020). This approach seems useful as early involvement may increase the likelihood that citizen science data are used in the design and monitoring of policies. Equal access to partnerships should not be assumed – there may be real or perceived power imbalances between stakeholders and trust may need to be built over time (Skarlatidou & Haklay, 2021).

An important role of national authorities in any water resource management framework is to respond to data and evidence with appropriate management action. Citizen science participants benefit greatly from receiving feedback about what their data shows and how the data have been used. They may even hold expectations about follow-up actions from the national authority, for example if an acute pollution event is detected. National authorities should be transparent with citizen scientists and other stakeholders about how their data will be used, both for monitoring and, where relevant, enforcement. It may be beneficial to publish written guidelines for the use of citizen science data. National authorities should also be prepared to share their own data and information freely with citizen scientists.

Is citizen science activity supported by dedicated funding and resources?

Although citizen science projects often rely on volunteers, they are not without cost. Funding is required for equipment, successful recruitment, trainings, communication, and feedback, as well as expense allowances. Funding is often project-based and thus short-term, and many water quality-related citizen science projects lack sufficient funding. Long-term strategies for funding citizen science projects that will be used to monitor indicator 6.3.2 are required. Projects can be funded by inter- and national authorities, but there are also many other funding streams available including public and private sector investment. Although citizen science is not free, a well-resourced and supported citizen science project has the potential to collect large amounts of data for a smaller per-measurement cost than conventional monitoring.

Freshwater Watch Nitrate and Phosphate testing. Credit: Earthwatch Europe

Credit: Max Andrey, Unsplash

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Uploading sample data, Lower Kafue. Credit: Ethel M, WWF Zambia

Proposed Pathways for Action

This brief outlines how connecting national authorities and international agencies with citizens scientists through data collection can lead to a more complete national water quality picture and, ultimately, to the protection and restoration of rivers, lakes and aquifers. We propose that data mobilisation and the SDGs serve as the catalysts to bring together national authorities and communities that will ultimately lead to the improvement of water quality (SDG target 6.3).

Through UNEP's implementation of SDG indicator 6.3.2, a clear picture emerged of the capacity of national authorities tasked with monitoring and assessing their freshwaters to fulfil their role. In the 2021 Progress Report, a clear link was established between GDP per capita and monitoring capacity with low-income countries reporting on only a small fraction of the total water bodies that were reported (UNEP, 2021). This means that without these data on water quality, the scientific basis for protection and restoration activities, and critically local understanding of the issues at stake are missing.

The report also made clear that despite a wealth of data in high-income countries, poor water quality was still reported. This highlights that collecting and assessing water quality data does not necessarily mean that good management will follow. These data are an essential prerequisite to appropriate management, but they are only one piece of the puzzle. For water quality to be protected or improved all stakeholders must have a voice and means to provide input and co-create solutions.

In this brief, we recognise that widespread adoption and integration of citizen science is urgently needed to make progress towards SDG target 6.3 and improve water quality. We propose that there is no 'one-size-fits-all' approach, and we suggest four action pathways that are based on availability of both national and citizen science data. There are four starting points based on data availability, summarised in Fig. 4.

National Authority Data Available	Citizen Science Data Available	Action Pathway
✓	✓	1. Focus on connecting initiatives and testing methods of integration, and building confidence in citizen science data
✓	✗	2. Focus on initiating or expanding citizen science programmes to dovetail with national authority programme
✗	✓	3. Focus on expanding national authority capacity with recognition of existing citizen science initiatives
✗	✗	4. Focus on simultaneous expansion of national authority and citizen science capacity in parallel

Figure 4. The four starting points based on data availability within national authority and citizen science initiatives, and how these relate to the four action pathways

Action Pathway 1: National authority and citizen science data both freely available

Focus on connecting initiatives and testing methods of integration and building confidence in citizen science data.

Where both national authority data and citizen science data already exist, citizen science data can complement existing national authority monitoring datasets by increasing the spatial and temporal availability of data. Volunteers already engaged in citizen science likely already possess knowledge about their local river which can be invaluable for water resource management. The priority in these cases should be the creation or solidification of an integrating framework to connect existing citizen science initiatives to one another and to the national authority. It will be necessary to find ways to integrate different datasets, for example by ensuring all projects have findable metadata explaining how they can be used effectively. Mechanisms to build confidence in all parties to use all the data should also be considered. Support and resources may need to be provided to enable citizen science projects to take part, with roles and responsibilities made clear to all stakeholders. Co-design of the framework with citizen science project coordinators and volunteers is paramount.

Priority questions:

- **Do all stakeholders have a shared understanding of their respective roles and responsibilities?**
- **Is citizen science activity supported by dedicated funding and resources?**
- **Can data be stored, accessed, reported and shared via suitable data management procedures?**

Case study: UK

The UK's devolved national authorities – the English Environment Agency (EA), the Scottish Environmental Protection Agency (SEPA), and Natural Resources Wales (NRW) – have a long history of monitoring water quality in rivers, with comprehensive datasets dating back to the 1990s. Similarly, many citizen science projects exist, some of which have been collecting relevant data since the mid-2000s. Recent investment from the private sector and charitable funding has supported the creation of the Catchment Systems Thinking Cooperative (CaSTCo). This project includes over 30 different stakeholders, who are co-designing a consistent approach for knowledge sharing as well as standardising data collection methods. The national authorities have not provided funding but have created specific roles within the organisation to understand how their work can be more aligned with citizen science activity, to establish guidelines for the use of citizen science data, and to provide support to citizen science projects.

One major challenge has been the diversity of different approaches used by existing citizen science projects and the lack of consistency between them. This has resulted in a situation where many different datasets are available, but they aren't easy to identify or combine. The model that is being adopted is to create an information-sharing 'ecosystem', with capacity-building initiatives supporting existing projects to share data with all stakeholders. This includes promoting consistent metadata and data models, as well as developing joined-up recruitment strategies, training resources, and feedback mechanisms for volunteers. The initiative is supported by Catchment Partnerships, which are legislatively backed multi-stakeholder groups responsible for working with the national authorities to produce river-basin management plans at waterbody level. This mechanism allows national authority representatives to communicate directly with citizen science project managers and volunteers about water resource management issues.

Freshwater Watch sampling, UK. Credit: John Hunt

Action Pathway 2: Limited availability of citizen science data

Focus on initiating or expanding citizen science programmes to dovetail with national authority programme.

Where there are plenty of national authority data but limited citizen science data, citizen science offers opportunities to complement or expand the existing monitoring network while simultaneously engaging with and involving the public in water resource management. Citizen science initiatives should be developed with these specific goals in mind. Attention should be given to the sampling locations and methodologies that will best complement the existing national authority network. This could include using citizen science to access remote or inaccessible areas, or to document local knowledge such as indigenous knowledge or semi-qualitative data not usually captured such as smells or phenomena like algal blooms. Significant support will need to be given to the recruitment and retention of volunteers. The desired governance structure of such projects will also need to be considered, for example whether they should be run by the national authority itself or by third parties with national authority support. Co-design of projects with volunteers is highly recommended to support long-term engagement.

Priority questions:

- **Are there strategies to recruit, train, and retain sufficient participants?**
- **Are there protocols to ensure ethical practice, inclusivity, and physical and mental health and safety?**
- **Are the (combined) data accurate, representative, and reliable at waterbody scale?**
- **Can data be stored, accessed, reported, and shared via suitable data management procedures?**

Case study: Kenya/Tanzania

The Water Resources Authority of Kenya (WRA) and Ministry of Water and Irrigation of Tanzania have come together to collectively monitor the world-renowned transboundary Mara River basin that drains into Lake Victoria. Both national authorities have extensive water quality monitoring programmes but recognise the potential to fill temporal and spatial data gaps using citizen science. They are also aware of the need to engage more meaningfully with local communities for water resource management. They had some prior experience with citizen science and were aware of its potential.

Water User Associations (Tanzania)/ Water Resource User Associations (Kenya) (known as W(R)UAs) are well-established in both countries and are built on a legislative framework. These community-based organisations comprise local stakeholders that ensure participatory governance of local water resources. In both countries these local associations have been involved with water quality monitoring and have established connections with the national authorities.

The model adopted in this Mara River basin project leveraged the connection that each national authority has with the W(R)UAs and used local offices to recruit, train and provide feedback directly. The W(R)UA members provided insight into monitoring locations and ensured representative sites were chosen. Data collection started in 2023, and interesting trends are already emerging relating to season and land use. The next steps include more in-depth analysis of the data and combination of the citizen science data with national authority data. Both national authorities are planning to expand to the whole Mara system, as well as other priority river basins, in their countries.

Top right and above: Testing for Nitrates and Phosphates in the Mara, Tanzania. Credit Rochi Mkole, LVBWB

Action Pathway 3: Limited availability of national authority data

Focus on expanding national authority capacity with recognition of existing citizen science initiatives.

Where citizen science projects are well-established but the national authority monitoring network has relatively limited or reducing capacity, attention should ideally be given first and foremost to expanding national authority capacity. However, in such cases citizen science has the potential to be an extremely valuable source of data provided the data are usable for SDG indicator 6.3.2. In these instances, national authorities should express the need for data to citizen science project coordinators, provide guidance on the specific scientific requirements, and make resources available to support citizen science groups with sustaining their projects and implementing any changes required. Data management procedures may need to be established to create pathways for data to easily reach the national authority.

Beyond the data, existing projects should also be viewed holistically – even where data are not suitable, citizen science projects are likely contributing to SDG6 by involving the public in water resource management. Therefore, respect should be given to the specific aims of individual projects, which may have value even if they do not align directly with national authority monitoring goals.

Priority questions:

- **Is citizen science activity supported by dedicated funding and resources?**
- **Can data be stored, accessed, reported, and shared via suitable data management procedures?**
- **Are the data accurate, representative, and reliable at waterbody scale?**
- **Can data be stored, accessed, reported, and shared via suitable data management procedures?**

Case study: Canada

Canada's expansive geography and relatively sparse populations pose challenges for large-scale coordinated national authority monitoring. The resulting lack of data has been identified as a major barrier to freshwater protection. However, a growing movement of Indigenous and non-Indigenous community-based monitoring and community science initiatives is bridging data gaps and leading freshwater stewardship in local watersheds. Monitoring groups of all sizes are collecting huge volumes of data – sometimes spanning decades. Data is stored in various places and formats, limiting secondary use and posing the risk of permanent data loss.

DataStream is an open access platform for sharing water quality and sediment quality data. It began in the Mackenzie River Basin, partnering with the Government of Northwest Territories to build a publicly accessible data platform to house results from 21 community-based monitoring programs. DataStream is now active in five hub regions across Canada, bringing data together at local and regional scales in standardised, analysis-ready formats that promote data access and (re)use. Importantly, monitoring programs that share their data on DataStream maintain ownership and responsibility for their data.

In the eight years since DataStream's initial launch, it has grown to offer comprehensive programming—from technical training to open data advocacy—and has dramatically improved the availability of water quality data in Canada. More than 260 different monitoring programs are sharing millions of unique water quality observations collected from over 50,000 sites in rivers, lakes, streams, and wetlands across the country. Over half of these data contributors are community-led initiatives.

Data on DataStream is being used in a **variety of ways** by communities, researchers, and governments. For example, data shared by community-based monitoring groups on DataStream has played a crucial role in **national assessments of Canada's freshwater**. The availability of this data has filled in gaps in regional assessments previously unable to receive a health score due to a lack of data.

Community-based monitoring in the Northwest Territories. Credit: Pat Kane LVBWB

Action Pathway 4: Limited availability of all data

Focus on simultaneous expansion of national authority and Citizen science capacity in parallel.

Where monitoring of any kind is limited, rapid increases in monitoring capacity are required. Complementing national authority monitoring with citizen science initiatives can introduce new monitoring sites quickly. National authority and citizen science monitoring strategies can be developed in parallel, meaning a strategic approach to monitoring programme design is possible. Citizen science monitoring locations and methodologies can be designed to fill gaps in national authority monitoring, and/or to engage specific populations in water resource management. Again, volunteer recruitment and retention is important for the maintenance of any citizen science program, so any citizen science monitoring programmes should be designed with sustained volunteer engagement in mind.

Priority questions:

- **Are there strategies to recruit and retain sufficient participants?**
- **Are there protocols to ensure ethical practice, inclusivity, and physical and mental health and safety?**
- **Are the data accurate, representative, and reliable at waterbody scale?**
- **Do all stakeholders have a shared understanding of their respective roles and responsibilities?**
- **Is citizen science activity supported by dedicated funding and resources?**

Case study: Sierra Leone

The National Water Resource Management Agency of Sierra Leone (NWRMA) was established in 2019. Since then, the agency invested heavily in capacity development and has ensured that staff are fully trained in water quality monitoring and assessment best practices. The agency has developed and implemented its first water quality monitoring programme in a single river basin: the Rokel River. This programme has combined both national authority and citizen science monitoring from the outset, and in 2023, Sierra Leone reported on SDG indicator 6.3.2 using a combined approach of citizen science and agency data.

The NWRMA is establishing a new analytical facility and two new regional offices. It has also used citizen science in the Rokel to help fill spatial data gaps and to ensure regular data are collected from remote river tributaries that are difficult to reach via conventional methods. Building on initial progress, the NWRMA is expanding monitoring beyond the Rokel, whilst simultaneously engaging more citizen scientists in the process. Designing a holistic monitoring strategy that incorporates both conventional and citizen science methodologies at its outset in this way allows the two data streams to seamlessly form one comprehensive assessment. Citizen science activity is already expanding to neighbouring basins, with a view to reach national coverage.

Quality assurance of the data generated by citizen science is critically important if it is to be meaningfully incorporated into national authority databases and used for policy or management. As part

Credit: NWRMA

of the monitoring programme design, the NWRMA have ensured that there is overlap between monitoring sites to allow for validation of the citizen science data against the data collected simultaneously through conventional, scientifically accredited methods. They have also compared the outputs of water quality assessments at the waterbody level using NWRMA data and citizen science data alone and found the overall classification of water bodies to be comparable.

In the Rokel River basin, the citizen scientists have more than doubled the amount of data available and are already involved in the development of the draft River Basin Management Plan. The NWRMA are also looking to expand the remit of citizen scientists to include biological and metals analysis, as well as investigating how to improve the engagement with, and feedback provided to, citizens for local water resource management. These lessons will be taken and used to improve the process as the expansion to national level proceeds.

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Uploading sample data, Tanzania. Credit: Rochi Mkole, LVBWB

The Future

We urgently need to increase the monitoring of ambient water quality globally. Without data and information on water quality, we cannot understand how much water is available for domestic use, what risks are associated with using this water, where these risks are emergent locally, or what water treatment capacity is needed now and into the future as the climate changes. Ideally these data will be locally relevant and accessible to the people who use the water directly, as well as those responsible for managing it, including local communities, water resource management authorities, and many others.

Citizen science for water quality monitoring has been an emerging topic for the last two decades but is now becoming mainstream. We know from global efforts to monitor biodiversity that citizen science data can be integrated into global indicators. We also know from existing citizen science water quality monitoring projects (both chemical and biomonitoring) that volunteers can collect high quality, relevant data, and undertake local actions to deal with identified risks. Citizen science also brings wider benefits, including education of volunteers, increased community involvement in water management, sharing of local knowledge, and the potential for immediate response to water quality incidents.

This is not to say that citizen science is a perfect solution. Citizen science for water quality monitoring is still relatively localised, with a small number of actors involved. Therefore, we should set realistic expectations for what can be achieved, particularly considering the need to align with volunteer motivations, interests, time, and resources. That said, there are clear pathways forward for growing citizen science in different contexts, presented in section 4 of this brief.

The exact actions that should be taken to promote citizen science for SDG indicator 6.3.2 monitoring in any given context depend on existing water quality monitoring and management capacity, as well as volunteer willingness to engage with national authorities. Consideration needs to be given to the scientific design of any monitoring programme, strategies to promote engagement and collaboration with volunteers, and the overall framework that allows national authorities and citizen scientists to share data and work together. Institutions considering citizen science should comprehensively consider how their project should be designed for the local context, ideally with help from public engagement experts. We hope that the checklist presented in section 3 of this brief can provide some initial guidance.

It is important to remember that although the costs are often reduced and decentralised compared to conventional monitoring, citizen science is not free. The types of funding required to support citizen science may differ from conventional water quality monitoring. For example, there may be a need to shift away from technical equipment and expertise and move towards financing resources that promote meaningful interactions between scientists and volunteers. Funders might be encouraged by the potential for both scientific outputs and science-society interactions.

Our experience suggests that integration of citizen science and national authority monitoring requires deliberate action. We urge national authorities to work with citizen science project coordinators and community organisations to do the following:

1. Nominate a focal point within your institution to explore the potential of citizen science for water resource management.
2. Task them with:
   a. Finding out which action pathway is best suited to your situation.
   b. Appraising your national monitoring capacity as reported through indicator 6.3.2 (available on the SDG Water Quality Hub).
   c. Exploring which citizen science projects have the most potential for your national context and establishing collaborations where appropriate (examples are available in chapter 2 of this document)
3. Consider the resources needed for implementation, including scientific design, strategies to promote engagement and collaboration with volunteers, and the overall framework that allows national authorities and citizen scientists to share data and work together.

Citizen science has the potential to revolutionise the way we manage water resources to improve water quality by making information readily available to those who need it most. We just need to mobilise it.

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