Global research agenda on sensor-based drinking water quality monitoring

Executive summary

BACKGROUND

Recent evidence suggests that as many as 4 billion people lack access to safely managed drinking water. One of the greatest challenges to ensuring safe water lies not in access alone, but in the ability to routinely monitor water quality. Traditional water quality monitoring—manual sampling, laboratory testing, and infrequent data—cannot meet the operational and regulatory needs of water systems in low-resource settings. Remote, low-cost, in-situ sensors (e.g., chlorine, turbidity, *E. coli* proxies) offer a promising alternative for generating continuous, actionable water quality data. However, successful adoption requires enabling policies, sustainable financing, appropriate technologies, capable institutions, and interoperable data systems. PATH, Cova Agua, and Mangrove Water have launched a technical working group (TWG) on remote drinking water quality monitoring as a global learning platform intended to improve awareness and technical knowledge on sensor-based monitoring technologies and approaches, strengthen collaboration among stakeholders, and harmonize advocacy and messaging communications.

PURPOSE

The TWG is developing a consensus-based global research agenda, building on recommendations from leading research articles and expertise from both practitioners and researchers alike. **The primary objective of this research agenda is to identify evidence gaps and research priorities specifically related to the operational requirements for effective implementation of remote monitoring of water systems in low-resource settings.** The agenda follows the United Nations Sustainable Development Goal 6 Global Acceleration Framework: governance, financing, innovation, capacity development, and data and information. A summary of the research questions can be found below.

COMPONENT AND EVIDENCE GAPS	RESEARCH QUESTIONS
Governance	
Core gaps: Weak institutional coordination, fragmented mandates, unclear data ownership, lack of interoperability, limited regulatory acceptance of digital evidence, insufficient capacity for interpreting and acting on sensor data, donor-driven fragmentation, and absence of standards for integrating real-time data into national compliance systems.	1. What institutional arrangements and accountability mechanisms enable timely action on water quality sensor alerts received by service providers? 2. How can real-time water quality sensors be integrated into daily operations and maintenance workflows to improve response time, reliability, and compliance with national water quality standards?
Financing	
Core gaps: High capital and operating costs, uncertain lifespan of low-cost sensors, limited evidence on cost-effectiveness, and lack of sustainable financing models. Opportunities include carbon markets, results-based financing, and water-quality benefit accounting, all of which require trustworthy, high-frequency data.	1. Landscape analysis: What are the cost(s) of sensor-based monitoring, including data management, capital expenditure, and operational expenditure for currently deployed/evaluated technologies? 2. What is the break-even point for cost-of-ownership for sensor-based monitoring technologies, considering current manual monitoring modes of operation for service delivery and monitoring? a. Landscape analysis of current (or idealized) manual vs. sensor costs among implementers—considering sensors manufactured locally, domestically, and internationally.

<table>
<tr><th>COMPONENT AND EVIDENCE GAPS</th><th>RESEARCH QUESTIONS</th></tr>
<tr><td></td><td>b. Landscape or case study analyses of cost-effectiveness across evidence-based case studies.
c. Analysis of willingness to pay for water quality (and sensor-based monitoring). <i>Note: Willingness to pay is inherently linked to capacity-building efforts, i.e. do end users understand and value water quality enough to pay extra for it. Would require willingness to pay analysis of water quality first, and then sensor-based monitoring.</i>
3. What are the possible financing/funding models for sensor-based monitoring, and what evidence exists for their effectiveness? Examples may include, but not limited to: carbon credits, results-based financing, government run lease to own schemes, and water quality benefits accounting.
4. How effective (within a predefined framework) are low-cost alternative sensors (i.e., US$100.00 or less) for chlorine? <i>Note: Defining “effective” is key (see technology and service innovation questions for additional notes).</i></td></tr>
<tr><td colspan="2"><h2>Technology and service innovations</h2></td></tr>
<tr><td>Core gaps: Limited availability of low-cost, validated sensors for chlorine and microbial contamination; lack of performance benchmarks; difficulty ensuring accuracy, calibration, and contextual suitability; absence of guidance on when sensors should replace, supplement, or not be used with manual methods.</td><td>1. What set of technical, performance, and validation requirements is best suited for the development and future applications/objectives of microbial and chlorine sensors in LRSs?
2. What social, political, financial, technical, and community barriers limit the development and deployment of remote microbial and chlorine sensors?
3. To what extent can alternative metrics for monitoring cost reflect more accurately the programmatic, operational, and health benefits from sensor-based water quality monitoring in LRSs? What case studies, published in literature or acquired from key informant interviews, can be documented as evidence?</td></tr>
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COMPONENT AND EVIDENCE GAPS	RESEARCH QUESTIONS
Capacity development	
Core gaps: Limited local capacity to install, maintain, and interpret sensors; unclear roles within service providers; insufficient digital literacy; weak institutional arrangements for sustaining systems beyond pilots; need for country-level demand and leadership; limited tools for assessing capacity readiness.	1. What technical and organizational skills do service providers need to deploy, run, and maintain sensor-based monitoring, and how do these differ from manual programs? 2. Which protocols, guidelines, and training methods are most effective for building both human and technical capacity among service providers, with a focus on empowering staff to install and maintain sensors, interpret sensor data, and make informed decisions that enhance water service delivery and safety? Address the identification of necessary roles and job levels for a successful program, as well as the development of targeted protocols for each role. 3. How do capacity development needs and strategies differ between the pilot phase and the scaling phase of sensor-based monitoring programs, and what mechanisms are required to ensure that capacity built during pilots is institutionalized and remains effective as programs expand? 4. What strategies and capacity-building approaches can be employed to generate sustained demand and clear direction at the government level for sensor-based water quality monitoring, ensuring alignment across the sector and supporting the institutionalization and scalability of these programs? 5. What institutional capacity-building requirements (technical, operational, and financial) are needed to enable regulators and local agencies to adopt, maintain, and act on sensor-based water quality data? 6. Can practical checklists of capacity needs for sustaining sensor-based water quality monitoring systems be created?
Data and information systems	
Core gaps: Fragmented data systems, poor interoperability, insufficient digital literacy, unclear data	1. How can data storage and ownership models be designed to balance accessibility, privacy, and regulatory compliance for sensor-based water quality monitoring systems in LRSs?

COMPONENT AND EVIDENCE GAPS	RESEARCH QUESTIONS
ownership/privacy models, weak integration of sensor data into existing government systems, and a lack of scalable architectures for real-time decision-making.	2. What are the most effective approaches for sharing real-time water quality data among stakeholders—including local governments, service providers, and communities—and how do these approaches impact trust, regulatory oversight, and service delivery? 3. What factors should be taken into account when scaling data systems from nonprofit organizations to government entities, specifically regarding data privacy and security, integration, access, usability, and cost implications? 4. What are optimal data architectures, data cost structures, and data systems that enable regulatory agencies, service providers, and consumers with the ability to access quality, real-time water quality monitoring data for accountability? 5. Can a short list of low-cost sensors and digital systems be created with clear protocols for use that would be widely applicable across the rural water sector? 6. What can be learned from the adoption and use of low-cost data sensors in proximate fields (e.g., air quality) to inform how people engage with, share, and use data?

Call to action

- **Drinking water service providers**: leverage these research questions to identify the operational feasibility, value-for-money, and strategic considerations for integrating remote water quality monitoring approaches into implementation plans, ultimately enabling more efficient and effective service delivery.
- **National government and regulatory agencies**: use these research questions to assess strategic, programmatic, and evidence requirements for sensor-based monitoring standards and practices.
- **Donors:** use the research agenda as a reference guide when working with grantees to design and/or evaluate drinking water service models.
- **Technology developers**: leverage this research agenda to better understand design requirements, target specifications, and contextual requirements necessary for sensor-based monitoring systems.
- **Academic researchers**: apply and refine the research questions to advance the evidence base on contextually and culturally appropriate and practical implementation models of remote water quality monitoring.

Introduction

Recent evidence suggests that as many as 4 billion people may lack access to safely managed drinking water — nearly double earlier estimates.[1] Yet one of the greatest challenges to ensuring safe water lies not in access alone, but in the ability to routinely monitor water quality. Traditional testing methods are costly, time intensive, and provide only periodic snapshots of water safety. Remote sensor technologies offer a promising alternative. Advances in low-cost, in situ sensors capable of detecting key parameters (e.g., chlorine residuals, turbidity, and *E. coli*) can provide real-time data to water service providers, enabling faster response to contamination events and improved accountability. While such technologies are well established in high-income settings, their application in low- and middle-income countries (LMICs) has been limited to small-scale pilots and research demonstrations. Strategic investment in scalable, interoperable remote sensing systems—coupled with policies that recognize and integrate digital data streams—could transform how water quality is monitored, helping ensure sustained access to safely managed drinking water worldwide.

With the intent to catalyze additional research on remote, sensor-based water quality monitoring for delivering safely managed water services in LMICs, the Technical Working Group on remote drinking water quality monitoring is launching a consensus-based global research agenda, building on recommendations from leading research articles and expertise from both practitioners and researchers alike. **The primary objective of this research agenda is to identify evidence gaps and research priorities specifically related to the operational requirements for effective implementation of remote monitoring of water systems in low-resource settings (LRSs).** We are applying the United Nations Sustainable Development Goal 6 Global Acceleration Framework as the basis for categorizing results (governance, financing, innovation, data and information, and capacity development). Following a discussion with the Core Advisory Team we broadened the titles of the themes to reflect a clearer and more comprehensive understanding of the SDG 6 acceleration framework as it relates to remote water quality monitoring.

This research agenda is primarily intended for drinking water service providers, public health officials, and regulators. The research questions are intentionally framed from a service-provision and operations point of view—to facilitate evidence generation on practical approaches demonstrating how water quality sensors can enhance routine monitoring, enable rapid response to contamination, and optimize treatment processes within service delivery models. We envision that the findings will also be relevant to researchers, academia, public health professionals, funding agencies and donors, the private sector, and civil society.

Each section, described below, includes a brief overview of the current state of evidence on a specific theme, followed by proposed research questions to further knowledge and capacity.

- **Governance:** Institutional structures and contextual requirements that influence the generation, flow, and use of sensor-based data.
- **Financing:** Capital and operational costs for deploying sensor-based monitoring systems and funding models for adoption.
- **Technology and service innovations:** Technical requirements and contextual/market barriers affecting the development and use of sensor-based technologies.
- **Capacity development:** Technical and organizational capacities and tools for service providers to deploy, operate, and manage sensor-based technologies at different scales.
- **Data and information systems:** Data system requirements, permissions, tools, and standard operating procedures needed for integrating sensor-based technologies for drinking water systems.

Governance

Water quality sensors have the potential to strengthen the delivery of safely managed drinking water services in LRSs. Remote sensing technologies are becoming more widely adopted and integrated into monitoring systems. It is necessary to enhance the evidence base on the value of these technologies from an operational and strategic perspective. Operational components of “doing things right” with these technologies can help operators and field technicians perform timely maintenance and carry out quality assurance and quality control functions. Strategic components—dedicated to “doing the right things,” like national ministries and regulatory bodies that ensure reliable data guides policy, investment, and regulatory frameworks—can significantly advance the worldwide provision of safely managed water services.

Low-cost water quality sensors and monitoring systems are increasingly accessible.[2,3] Sensor-generated data have proven valuable for improving operational decision-making by utilities and community managers, enabling early warning and rapid response, and supporting advocacy efforts by civil society to inform local authorities.[4,5,6] Despite these successes, multiple barriers continue to hinder the integration of sensor-based water quality monitoring into policy, regulatory, and data-governance systems in LMICs.[7,8]

Institutional coordination challenges combined with fragmented responsibilities across ministries further complicate the integration of sensor-based water quality monitoring data into governance frameworks.[7,8] Without interagency data-sharing agreements or accountability protocols, sensor data often fall into institutional gaps and are therefore not used for national reporting or to generate evidence to inform government policies. Community sensor pilots often fail to connect with national compliance systems due to infrastructure gaps.[9] Donor-driven technology choices create nonharmonic systems,[7,10] while limited capacity for installation, calibration, and interpretation limits the likelihood of sustainability of individual projects.[11,12] Trust issues persist as data from non-state actors lack formal recognition, and regulatory frameworks rarely accept digital or artificial intelligence–assisted evidence.[13,14] Legacy databases optimized for static sampling reports, weak interoperability, lack of open standards, and poor verification processes also hinder adoption.[15] Finally, scaling requires treating data as a public good, aligning with regulations, and establishing financing and accountability mechanisms to support long-term monitoring.[7,10]

Specific examples illustrate these challenges. Multiple Internet of Things (IoT)–enabled pilots in tourist and industrial regions detected exceedances of national drinking and environmental water standards but remained outside regulatory frameworks.[13,14] In Indonesia, Semtech Corporation's LoRa®-based sensor systems in Lake Toba operate outside formal compliance despite national monitoring networks.[16] Kenya's pilots face regulatory requirements for manual sampling,[12] and India's continuous effluent monitoring systems suffer from weak enforcement and auditing.[17] Sustained use of sensor systems requires human and institutional capacity to install, calibrate, maintain, and interpret data—yet competencies are often scarce among LMIC regulators.[9,12] These examples illustrate the importance of considering the governance frameworks required for sensor-based water quality monitoring.

In summary, current governance and policy gaps related to water sensors identified by Thomas and Brown[8] highlight several interconnected challenges. Sensor data are often weakly integrated into formal governance and decision-making systems, limiting their influence on water quality management and service delivery.[8] Accountability gaps persist between donors, governments, and service providers, with unclear roles and incentives for acting on performance data.[8,10] The absence of standards for data ownership, privacy, and interoperability undermines transparency and coordination across institutions,[7] while limited regulatory and financial frameworks for treating monitoring data as a sustained public service ("data as a service") constrain long-term viability.[10] In addition, many local utilities and regulators lack the capacity to interpret and act upon sensor information,[11] and donor-driven technology choices frequently lead to fragmented, nonharmonic systems that weaken national ownership and accountability.[7,10] These challenges highlight the need for governance frameworks that align decision-making to ensure data and institutional processes reinforce sustainable, accountable water service delivery at operational (e.g., application and reliability), tactical (e.g., institutional models and accountability), and strategic levels (e.g., policy integration and governance reform).[18]

RESEARCH QUESTIONS

1. What institutional arrangements accountability mechanisms enable timely action on water quality sensor alerts received by service and providers?
2. How can real-time water quality sensors be integrated into daily operations and maintenance workflows to improve response time, reliability, and compliance with national water quality standards?

Financing

Provision of water that is safely managed, which the United Nations Children's Fund (UNICEF)/World Health Organization (WHO) Joint Monitoring Programme for Water Supply, Sanitation and Hygiene defines as available when needed, on premises, and free of priority contaminants, requires routine operational and outcome monitoring to allow for responsive management. However, this incurs considerable cost, driven by use of staff time, reagents, equipment, and transport.[19,20]

Sensor-based water quality monitoring offers one technological solution to this challenge, supplying an increased frequency of data often transmitted remotely. Sensor-based monitoring data can also improve response time and support a preventative approach to support systems, in turn improving potential health outcomes. There remain a number of critical technology questions and regulatory questions for sensor-based water quality monitoring to go to scale,[21] however, complementary to these considerations is the biggest potential barrier: cost.

For many technologies that monitor *E. coli* and chlorine in real time, the historical market has been water utilities and municipalities in high-income countries. Therefore, low-cost technologies remain underdeveloped, under evaluated, or challenging to procure. Current research and implementations indicate that cost per unit is widely variable based on context, the purchasing entity, and the technologies/sensors being purchased.[22] However, critical consideration should be given to not just the up-front capital expenditure of sensor-based monitoring but also the benefits of this monitoring. Evidence from sensors for monitoring water access and functionality indicates that sensors can improve local capacity to respond to and preempt system downtime, improving access. Therefore, if applied to water quality, it is plausible that water quality monitoring using sensors could improve health outcomes. Thus, cost-effectiveness, that is, the relative benefit (as defined) per unit of cost, is a critical metric to measure and consider.

Although cost-effectiveness is the most obviously important framework to consider, most implementers of water, sanitation, and hygiene (WASH), particularly in LMICs, are funding constrained. They are often forced to weigh cost over cost-effectiveness, particularly for technologies with unproven lifespans, due to limited budgets and timelines. A number of alternative funding pathways exist that might enable or require the frequency and utility of data provided by drinking water quality sensors, which could allow for cost-effectiveness to be weighed over cost. Several key emerging examples have shown promise that water quality results can translate to funding and financing opportunities, including carbon credit markets,[23] results-based funding,[24] and water quality benefits accounting.[4] These opportunities all hinge on the accuracy and frequency of reported data, which suggests that sensor-based monitoring could enable increased access to these models.[25]

RESEARCH QUESTIONS

1. Landscape analysis: What are the cost(s) of sensor-based monitoring, including data management, capital expenditure, and operational expenditure for currently deployed/evaluated technologies?

2. What is the break-even point for cost-of-ownership for sensor-based monitoring technologies, considering current manual monitoring modes of operation for service delivery and monitoring?
    a. Landscape analysis of current (or idealized) manual vs. sensor costs among implementers—considering sensors manufactured locally, domestically, and internationally.
    b. Landscape or case study analyses of cost-effectiveness across evidence-based case studies.
    c. Analysis of willingness to pay for water quality (and sensor-based monitoring). *Note: Willingness to pay is inherently linked to capacity-building efforts, i.e. do end users understand and value water quality enough to pay extra for it. Would require willingness to pay analysis of water quality first, and then sensor-based monitoring.*
3. What are the possible financing/funding models for sensor-based monitoring, and what evidence exists for their effectiveness? Examples may include, but not limited to: carbon credits, results-based financing, government run lease to own schemes, and water quality benefits accounting.
4. How effective (within a predefined framework) are low-cost alternative sensors (i.e., US$100.00 or less) for chlorine? *Note: Defining "effective" is key (see technology and service innovation questions for additional notes)*

Technology and service innovations

Safe drinking water is defined by the UNICEF/WHO Joint Monitoring Programme for Water Supply, Sanitation and Hygiene as water that is available on demand, accessible on the premises, and is free from priority chemical and microbial contamination.[20] For nearly half of the population in LMICs lacking safely managed drinking water services, fecal contamination has been identified as the primary barrier.[19] Data on drinking water quality in LRSs across the world are extremely spatially and temporally limited and are often of poor quality where they are available. Existing data are insufficient to quantify the effects of pollution and accurately model exposures, preventing effective identification of (un)safe water quality, accountability of service providers, and tracking toward national and global water goals.[21] Periodic monitoring is critical to ensure functionality of systems and services as well as the quality of water. Routine water quality monitoring typically includes a combination of pH, turbidity, chlorine, and temperature, which indicate operation treatment effectiveness and are sometimes proxies for potential contamination. In LRS contexts, consistent water quality monitoring is inhibited by the need to travel for field sampling, the cost of equipment, and technical expertise.[22] These challenges are exacerbated in microbial monitoring, where accepted methods for presence or enumeration require field sampling, consumables, and laboratory analysis or incubation periods.[23,24]

In response to challenges and limitations of field sampling for water quality data, in situ sensors have become a research focus and practical tool for tracking water safety and the efficacy of treatment processes. Historic in situ and remote monitoring in an LRS has primarily focused on functionality of WASH services, such as hand pumps or solar-powered pumps in boreholes.[4,25,26] Existing sensors to monitor chlorine residual and microbial contamination in LRS contexts are lacking. Existing field-based methods[7] and in situ sensors for chlorine monitoring may be done with colorimetric or electrochemical and optical methods, respectively,[27,28,29] but the latter still lacks considerations for cost-effectiveness, field-based validation evidence, and stable power and internet infrastructure where needed. Microbial detection typically requires culturing or molecular techniques in a lab, not easily miniaturized for field deployment or conducive to providing real- or near-time results.[30] While sensor-based monitoring for microbial contamination is lacking, even in high-income contexts, an emerging class of fluorimeters measuring a wavelength of fluorescence highly correlated to fecal indicator bacteria—such as total coliforms, thermotolerant coliforms, and *E. coli*—known as tryptophan-like fluorescence, have been the focus of research.[23,31,32] A low-cost tryptophan-like fluorescence sensor and machine learning model have been developed and recently deployed in pilot projects across surface waters in high-income countries, offering a potential route for further research, development, and application.[33]

Existing barriers for the development and application of chlorine and microbial sensors are technical, as stated above, as well as policy/institutional, financial, and social. Gaps in the literature exist around technical specifications for technology designs that are contextualized to highlight applications where sensors can supplement, replace, or not be used with existing monitoring methods. This should specifically focus on the benefits that sensors offer to operators in service delivery, transparency, and safety to consumers, compliance with regulatory authorities, and tracking global goals. Recommendations for monitoring of microbial contamination from WHO and approved methods from the International Organization for Standardization consist of culture-based methods, where any presence of *E. coli* (0 CFU/100 mL) can be detected.[34,35] Sensor-based methods may not necessarily need to achieve these same standards to be an effective process control and monitoring tool, but further research is needed to identify accuracy and detection limit requirements to align with WHO and United Nations Sustainable Development Goal objectives. Regulatory and recommended concentrations of free chlorine residual in drinking water systems, ranging between 0.2 and 5.0 mg/L and measured monthly, are a target for remote monitoring technologies to support requirements for institutional/national compliance, as well as to benefit process control.[36] Financial constraints remain a significant barrier for program and government implementation of sensor-based monitoring. While cost is typically assessed from the capital or operating and maintenance expenditures, further research, presented as case studies, should identify an alternative approach to assessing the *cost-effectiveness* of a program or water system with sensor-enabled monitoring in its ability to more consistently and at higher volumes deliver microbially safe drinking water (the key metric as reduced $ per L of safe water delivered before/after use of sensors).

RESEARCH QUESTIONS

1. What set of technical, performance, and validation requirements is best suited for the development and future applications/objectives of microbial and chlorine sensors in LRSs?
2. What social, political, financial, technical, and community barriers limit the development and deployment of remote microbial and chlorine sensors?
3. To what extent can alternative metrics for monitoring cost reflect more accurately the programmatic, operational, and health benefits from sensor-based water quality monitoring in LRSs? What case studies, published in literature or acquired from key informant interviews, can be documented as evidence?

Capacity development

Sensor-based, remote water quality monitoring offers transformative potential for drinking water systems in LRSs, enabling real-time tracking of critical parameters such as turbidity, pH, and microbial contamination through IoT sensors, cloud platforms, and satellite-linked systems. However, successful implementation requires robust capacity development at multiple levels and is significantly different from a manual water quality monitoring program. Local technical staff must be trained not only to install and maintain sensors rather than only perform water quality tests, but also to interpret and act on the data they generate, integrating these insights into existing asset management and regulatory frameworks.[37,38,39] These different roles require specific support and capacity-building. Building digital literacy and fostering data-driven decision-making are essential, as is the development of user-centered systems that are responsive to the realities of rural and underserved communities.[40,41] Ongoing support, refresher training, and peer-to-peer learning are highlighted as critical for sustaining these systems and ensuring that technology adoption leads to meaningful improvements in water safety and service reliability.[39,42]

Beyond technical skills, capacity development must address systemic and organizational needs. Countries and service providers require mandates, resources, and integrated platforms to collect, manage, and use water quality data from diverse sources, including households, utilities, and public facilities.[2,43] Investments should shift from a focus solely on infrastructure to supporting continuous monitoring, maintenance, and data use for equitable service delivery.[44] Effective remote monitoring also depends on transparent data sharing, clear roles and responsibilities among stakeholders, and mechanisms for translating data into actionable insights at both national and local levels.[41,45] Ultimately, building capacity for remote water quality monitoring means not just training individuals, but also strengthening institutions, policies, and partnerships to ensure that sensor data leads to sustainable improvements in water safety and access.[37,39]

Practical follow-up: Aquaya had some of the clearest frameworks and also research that covered the sector. They would likely be great to lead this effort and expand on it.

RESEARCH QUESTIONS

1. What technical and organizational skills do service providers need to deploy, run, and maintain sensor-based monitoring, and how do these differ from manual programs?
2. Which protocols, guidelines, and training methods are most effective for building both human and technical capacity among service providers, with a focus on empowering staff to install and maintain sensors, interpret sensor data, and make informed decisions that enhance water service delivery and safety? Address the identification of

necessary roles and job levels for a successful program, as well as the development of targeted protocols for each role.

3. How do capacity development needs and strategies differ between the pilot phase and the scaling phase of sensor-based monitoring programs, and what mechanisms are required to ensure that capacity built during pilots is institutionalized and remains effective as programs expand?
4. What strategies and capacity-building approaches can be employed to generate sustained demand and clear direction at the government level for sensor-based water quality monitoring, ensuring alignment across the sector and supporting the institutionalization and scalability of these programs?
5. What institutional capacity-building requirements (technical, operational, and financial) are needed to enable regulators and local agencies to adopt, maintain, and act on sensor-based water quality data?
6. Can practical checklists of capacity needs for sustaining sensor-based water quality monitoring systems be created?

Data and information systems

Sensor-based, remote water quality monitoring is rapidly advancing, with digital tools such as IoT sensors, cloud-based dashboards, and mobile networks enabling real-time, scalable, and geospatially rich data collection for drinking water systems in LRSs. These technologies allow for continuous tracking of key indicators like turbidity, pH, and microbial contamination, and are increasingly being integrated into asset management and regulatory frameworks.[37,39,42] However, the current state of knowledge reveals that most global water quality monitoring still relies on infrequent household surveys, which are inadequate for capturing dynamic changes due to climate or policy shocks. Peer-reviewed analyses and professional forums highlight the promise of digital systems but also point to persistent gaps in data integration, timeliness, and coverage—especially for chemical contaminants and public facility water use.[2,43]

The main challenges and research gaps include fragmented data systems, lack of interoperability, insufficient technical and digital literacy among local staff, and limited mechanisms for translating data into actionable insights.[39,41,42] To move forward and make these systems replicable and scalable, the literature calls for investments in integrated data platforms that combine information from households, utilities, and public facilities; continuous monitoring and capacity development for data interpretation and system maintenance; and policy-driven approaches that ensure data is used for equitable and sustainable service delivery.[44,45] Relevant stakeholders include local service providers, government agencies, nongovernmental organizations, technology vendors, and community members, all of whom must collaborate to ensure data is trusted, shared, and acted upon. Key considerations for scaling data systems involve not only determining which local government platforms will receive and use the data, but also how to expand the system effectively. This process raises important questions about ensuring privacy and security when using cloud-based solutions, integrating new data streams into existing infrastructure, maintaining robust data protection, and managing system costs. Ultimately, robust data and information systems are essential for improving drinking water service provision and achieving universal access to safely managed drinking water, as they enable timely detection of risks, informed maintenance, and targeted investments where they are needed most.[37,39,41]

Practical follow-up: The following organizations would be good ones to help provide input based on things shared during the Technical Working Group meetings: Helvetas (Marisa Ruoss), Cova, Virridy, and the Development Innovation Lab at the University of Chicago.

RESEARCH QUESTIONS

1. How can data storage and ownership models be designed to balance accessibility, privacy, and regulatory compliance for sensor-based water quality monitoring systems in LRSs?
2. What are the most effective approaches for sharing real-time water quality data among stakeholders—including local governments, service providers, and communities—and how do these approaches impact trust, regulatory oversight, and service delivery?
3. What factors should be taken into account when scaling data systems from nonprofit organizations to government entities, specifically regarding data privacy and security, integration, access, usability, and cost implications?
4. What are optimal data architectures, data cost structures, and data systems that enable regulatory agencies, service providers, and consumers with the ability to access quality, real-time water quality monitoring data for accountability?

5. Can a short list of low-cost sensors and digital systems be created with clear protocols for use that would be widely applicable across the rural water sector?
6. What can be learned from the adoption and use of low-cost data sensors in proximate fields (e.g., air quality) to inform how people engage with, share, and use data?

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