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Research Paper

Challenges and opportunities for enhancing groundwater data access and usability in low- and middle-income countries: insights and recommendations from WaSH researchers and practitioners

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ABSTRACT

Groundwater provides more than half of all water for drinking and irrigation worldwide. Monitoring and managing groundwater resources is essential to achieve the Sustainable Development Goals. However, groundwater resources need to be better monitored. We explored practical approaches to improve groundwater monitoring for informed decision-making, focusing on low- and middle-income country settings. Case studies from a 2023 UNC Water and Health Conference side event highlighted innovative approaches, including open-source data modeling, groundwater monitoring in humanitarian contexts, and using *in situ* sensors to monitor drought resilience. The case studies described field data integration, remote sensing, and technology (e.g., Modflow-USG, ModelMuse, Drought Resilience Impact Platform). Barriers to groundwater data use were identified by side event participants, including inadequate data access, insufficient collaboration and leadership, and challenges in integrating diverse data and technology. Side event recommendations included creating a central groundwater monitoring data repository, building greater hydrogeology capacity in the WaSH sector, and increasing funding for data collection and monitoring. We urge government leaders to develop regulations and build internal capacity for sustainable groundwater management. This comprehensive approach aims to address challenges and promote informed decision-making for the long-term sustainability of groundwater resources.

Key words: drought resilience, groundwater monitoring and modeling, *in situ* sensors, open-source data modeling, Sustainable Development Goals, water resource decision-making

HIGHLIGHTS

- Described practical applications showcasing open-source modeling, active monitoring, and *in situ* sensors.
- Challenges include data access, leadership, and tech integration hindering groundwater data use.
- Need to balance community needs and secure sustainable funding.
- Call for a centralized repository, capacity-building, increased investment, and governmental leadership for informed groundwater decision-making.

INTRODUCTION

Groundwater is a crucial source of water for drinking and agriculture that accounts for 99% of all liquid freshwater (UNESCO World Water Assessment Programme n.d.). Estimates suggest that groundwater provides almost half of all water for drinking and irrigated agriculture worldwide (Siebert *et al.* 2010; Zektser & Everett n.d.). However, using groundwater for sustainable development requires careful monitoring and management, as an estimated 1.7 billion people live in areas where groundwater is being over-exploited (Gleeson *et al.* 2012). Groundwater monitoring gathers information on how water levels fluctuate in the subsurface and, when combined with information on aquifer properties, can inform on groundwater recharge, groundwater movement, and the sustainability of groundwater extractions.

Groundwater monitoring and management is essential to achieving Sustainable Development Goal (SDG) 6, which calls for the availability and sustainable management of water, sanitation, and hygiene (WaSH) by 2030. Target 6.5 calls explicitly for integrated water resource management (IWRM) involving WaSH, agriculture, and other relevant sectors to ensure positive social, economic, and environmental impacts. Although a much smaller user of groundwater than the agriculture sector, WaSH sector professionals can support the long-term sustainability of groundwater sources by making informed decisions about groundwater extraction (National Ground Water Association 2024).

To meaningfully participate in IWRM, the WaSH sector must develop a more robust understanding of groundwater resources – currently, groundwater resources are poorly monitored in many regions (Famiglietti 2014). This is especially true in low- and middle-income countries with limited government capacity to develop and implement comprehensive groundwater management policies and regulations (Rodell *et al.* 2009). Without such a framework, WaSH professionals in low-resource settings face additional challenges in making informed decisions about groundwater resources. Better understanding these challenges and identifying the tools and resources to overcome them is one step toward ensuring that the WaSH sector contributes to the long-term sustainability of groundwater resources.

The Water Project, The Water Institute at the University of North Carolina (UNC) at Chapel Hill, the Mortenson Center in Global Engineering & Resilience at Colorado University (CU) at Boulder, Groundwater Relief (GWR), and the Millennium Water Alliance (MWA) organized a side event on the practical uses of groundwater monitoring and modeling data in low-resource settings at the UNC Water and Health Conference on 26 October 2023. The objectives of this side event were to identify and discuss established methods for groundwater data collection and analysis, identify practical uses for groundwater data to support decision-making, and describe barriers and opportunities to use these data effectively in a resource-limited context. This paper explains the themes and recommendations from presentations, panel discussions, and group discussions.

METHODS

The side event, 'Practical uses of groundwater monitoring and modeling data for WaSH researchers and practitioners', started with an overview, a scene-setting presentation, and brief presentations describing three case studies on groundwater data use. The case studies highlighted existing methods and opportunities for groundwater data use in program planning and decision-making. Geraint Burrows, Chief Executive Officer of Groundwater Relief, presented on manual groundwater monitoring, highlighting how engagement with local governments and academia improved planning for the Rohingya refugee camps in Bangladesh. Denis Muthike, a Research Associate from CU Boulder, described using *in situ* sensor technology to conduct real-time groundwater monitoring to predict and improve resilience to drought in East Africa. Silvia Landa, a researcher for The Water Institute at UNC, discussed using open-source data and software to model groundwater in western Kenya, where a collaboration between The Water Institute at UNC and The Water Project informed more sustainable drinking water project planning.

A panel discussion followed. The panelists included the case study presenters, Spencer Bogle, Director of Programs for The Water Project, and June Samo, WaSH Systems Manager for Millennium Water Alliance. Panelists elaborated on the information presented during the case studies and answered audience questions.

Of the 45 people who attended the in-person event, 35 participated in discussion groups. Participants were divided into four groups. The participants were mostly from academia, non-governmental organizations, and corporate/private organizations. The majority (75%) reported having previously used groundwater data in their work. Participants brought experience from various settings and countries to the discussion, so the geographic focus of our findings and recommendations is global. Panelists led the discussions using a list of questions. Participants described their experiences using groundwater data in resource-limited contexts and identified the challenges and opportunities most prevalent in their work. After the discussions, the groups reconvened to share their findings and identified the next steps for participants who wish to continue collaborating. Synthesis of the experiences and insights shared during the discussion groups is summarized in the Results and Discussion section.

RESULTS AND DISCUSSION

Opportunities for groundwater data use: case studies

The first two case studies presented during the side event session describe established groundwater monitoring methods: manual monitoring conducted by borehole operators in a refugee settlement in Bangladesh, and *in situ* sensor monitoring to increase drought resilience in an arid region of Kenya. Both highlight opportunities to use data for decision-making. The third case study describes a technique for consolidating field data and remote sensing to model groundwater for decision-making in western Kenya. It highlights opportunities for learning and intentional groundwater management even when groundwater monitoring data is limited. Additional information and figures on the case studies are available in the Supplementary material.

Case study 1: Groundwater monitoring and its application in humanitarian response

In a humanitarian context, groundwater monitoring is often undertaken in production wells (rather than dedicated monitoring wells) by a borehole operator. It involves collecting data on static and dynamic water levels, quality testing, and daily production. Such monitoring helps the water provider identify the status of their groundwater infrastructure and provides early warning of potential problems. Hydrogeologists can use monitoring to understand and model the aquifer systems better and help authorities improve the sustainable management of these resources.

GWR's involvement in the Rohingya refugee response between 2017 and 2023 illustrates the importance of groundwater monitoring within humanitarian work. In August 2017, an outbreak of violence in Rakhine State, Myanmar, caused a massive influx of 900,000 Rohingya people to settle in Cox's Bazar, Bangladesh. Most refugees (around 760,000 people) were settled in the Kutupalong Expansion Site, referred to as the Mega Camp. As the aquifers in those newly occupied areas started to be pumped at unprecedented rates, concerns were raised about the sustainability of groundwater and how new abstractions might impact host community water sources. In collaboration with Medecins Sans Frontières Holland (MSF-OCA), GWR initiated the first monitoring program at the Mega Camp in January 2018. Data were collected manually with dip meters and automatically with *in situ* data loggers. This monitoring program has since been maintained up to the time of writing this note.

Monitoring data was used to evaluate the impact of proposed piped water networks that would pump water from production wells and then distribute it to the refugees by gravity. In 2019, GWR, in collaboration with Dhaka University, was commissioned by the International Organization for Migration (IOM) with funding from the Government of Japan to develop a groundwater model of the aquifer system. The MSF-OCA monitoring records formed the principal dataset for groundwater model calibration.

A groundwater modeling package called MODFLOW-USG (UnStructured Grids) was used to construct the Cox's Bazar Groundwater Model. The groundwater model provided significant insight into the region's principal aquifer systems. Once the numerical model had been tested and shown to reasonably reproduce past behavior (as demonstrated by the monitoring data), it was used to forecast future groundwater behavior at the Camp based on proposed plans. The groundwater model predicted that groundwater levels within the center and its vicinity would decline until 2022 when a new equilibrium would be reached. Groundwater levels were predicted to decrease by over 20 m in the center of the camp, and the cone of depression was expected to extend for several kilometers north of the Mega Camp (Burrows *et al.* 2020).

The monitoring records were reviewed by GWR in December 2023 and compared with the groundwater model outputs of 2019. The following observations were made from the data:

- Following a period of decline, groundwater levels are generally stabilizing and reaching a new equilibrium. This is despite a marked reduction in rainfall over 2022.
- The groundwater model performed reasonably well in forecasting long-term trends.

Case study 2: Improving water security decisions using *in situ* sensors

The arid and semi-arid regions of northern Kenya are among the most vulnerable areas of the world to climate impacts. These regions support the livelihoods of millions of indigenous people who depend heavily on drought-risk-prone pastoralist systems. These risks are compounded by a lack of reliable water supply during drought due to the relatively underdeveloped groundwater systems and the limited availability of surface water sources (Shiferaw *et al.* 2014). Borehole functionality is critical decision-enabling information for local communities and drought agencies in these regions. Monitoring functionality using manual systems, as has been the case in such remote areas, can be expensive and sometimes ineffective (Swan *et al.* 2018). Alternative methods that provide automation for collecting and reporting functionality data are thus critical in preventing humanitarian crises and livelihood losses. The Mortenson Center in Global Engineering & Resilience at CU Boulder innovated a groundwater monitoring service with the Millennium Water Alliance to support drought resilience for rangeland indigenous communities. The Drought Resilience Impact Platform (DRIP) service monitors groundwater sources for more than three million people in northern Kenya using *in situ* sensors connected to satellites for near real-time reporting (Thomas *et al.* 2020).

DRIP integrates early detection of borehole system failures to support planning for proactive groundwater management to ensure water availability for the dryland communities, preventing humanitarian crises during the dry seasons (Thomas *et al.* 2020). The satellite-connected sensor reporting was a timely and critical intervention for the local communities and the drought agencies, resulting in improved borehole maintenance, facilitating sustained uptime, and providing a reliable water supply for people and livestock. Another component of the DRIP service is the integration of remote sensing and geospatial analysis with the near real-time reporting of borehole functionality. This integration using machine learning models enables spatial-temporal groundwater use and demand forecasting. The predictions rely on the borehole runtime, converted into a yield metric (liters/capita/day) as the model response variable (Fankhauser *et al.* 2022). These forecasts help understand and anticipate areas experiencing water stress across northern Kenya.

The DRIP service relies on a solid partnership between the implementers, local communities, government agencies, and humanitarian agencies. This cooperation and coordination have resulted in more than 8 years of successful service delivery, including the novel groundwater drought forecasting that has improved the decision-making processes for the Kenya National Drought Management Agency and the Kenya Red Cross Society. Borehole functionality based on pump runtime data is shared with these partners through monthly bulletins and an online dashboard that is accessible publicly to support borehole repair decisions. The data triggers borehole repairs, anticipates water stress, and identifies when communities need temporary water trucking.

Case study 3: The use of field data, remote sensing, and open-source software for groundwater modeling in Kenya

The Water Project and The Water Institute at UNC developed a groundwater model for Kenya's Vihiga and Kakamega counties. This initiative is an initial step to prevent over-extraction and plan for the impact of climate change using a combination of field data, remote sensing, and open-source software because of resource and primary data limitations. The field data included static water level, well depth, and hydraulic conductivity. The Water Project provided hydrogeological assessments conducted during borehole implementation (used to assess lithology), data from regular monitoring of boreholes and hand-dug wells, and additional data from a mapping initiative where other water points in the region were identified and inspected. The Water Project had yield extraction data for 1,739 wells and static water level data for 88 wells. Field data was supplemented by remote sensing data sources like World Resources Institute and HydroBASINS for watershed boundaries (HydroSHEDS n.d.; World Resources Institute 1992; Lehner & Grill 2013), NASA's SRTM for digital elevation (Kobrick & Farr 2000), NASA's Global Precipitation Model and UCI's remote sensing for precipitation, NASA's MODIS and GloDET for evapotranspiration, and NASA's GLDAS for root zone soil moisture. Open-source groundwater modeling software was evaluated, including iMOD, MODFLOW OWHM, IWFM, WRF-Hydro, Parflow, and dfnWorks (Montoya 2021). FloPy was initially considered for its versatility (Bakker *et al.* 2016). However, ModelMuse was ultimately selected (Winston 2019) for its user-friendly interface, compatibility with other tools, integration with MODFLOW, and extensive support and user base. AquiMod was not included in the initial model scoping but could be considered for future work because of its applicability in data-scarce regions (British Geological Survey 2024). QGIS can be used to edit remote sensing data to support the modeling process (QGIS n.d.).

The Water Project and The Water Institute identified data gaps and areas for improvement in our data collection and modeling approaches. Ideally, remote sensing data can be calibrated with local field data, but access to field data was limited. Incorporating data from pumping tests, borehole log data, additional observation wells, and river field observations was recommended to enhance model accuracy. While the model looks at the data at a point in time, transient modeling could be used to reflect the variations of wet and dry seasons. Integrating the Stream Package into MODFLOW with associated river data would more effectively represent the interaction between groundwater and rivers. With improved model accuracy, the groundwater modeling process can be applied to various decision-support scenarios, such as determining additional well locations or extraction amounts, assessing impacts from climate change, development, or population growth, and monitoring changes in groundwater levels over time. During the panel discussion, we discussed the model's limitations, noting difficulties in achieving high R^2 values in model calibration when there is little field data. Despite constraints, the model is a valuable diagnostic tool to guide stakeholder conversations on the appropriateness of different interventions (e.g., rainwater harvesting, groundwater extraction, groundwater recharge) in focus counties. The model helped The Water Project identify the data needed to improve future model iterations' accuracy and decision-making power.

Barriers to groundwater data use

Inequitable access to usable and actionable data

Side event participants reported varying degrees of success in accessing existing groundwater data and identified a need for data to be publicly available in a usable format. Many expressed the need for centralized, consistent longitudinal data collection (Wagaba *et al.* 2023).

Data are often shared in PDF reports, limiting their use for analysis and aggregation (Nussbaumer *et al.* 2016). Notices provided by contractors (hydrogeologists, drillers, etc.) are often provided on paper (Nussbaumer *et al.* 2016). Data collectors store hard copies that are not circulated or published and can be lost. Even when paper records are digitized, this process can be time-consuming (Danert *et al.* 2022) and limit the usefulness of both the data and the digitization. Different contractors collect different data, which restricts comparison or long-term tracking use.

Sharing data will reduce cost barriers related to primary data collection; side event participants reported that partnerships with larger donor organizations allow them to collect data, but it has been reported elsewhere that donor timelines can force rushed siting processes (Wagaba *et al.* 2023). Similarly, side event participants expressed frustration with the disparities in the time it takes for different actors to release data. For example, academic researchers collect data, but the publication process can hinder decision-makers access to those data.

Many side event participants use the Africa Groundwater Atlas developed by the British Geological Society. Many of the data in The Atlas are fundamental properties of the groundwater system that do not change with time. However, for data with a temporal aspect, participants seek a resource that is regularly updated to ensure that they are making decisions based on accurate information without unnecessary or redundant data collection costs.

Side event participants expressed concerns about over-extraction if groundwater use data are not centralized, and groups need to know about other demands on surveyed aquifers. They stated that knowing where test wells were dry or had insufficient yield would be beneficial and save substantial costs and time. One participant reported that because they are starting with no data in most new borehole drilling projects, they often drill two or three wells before a site with adequate productivity is found, increasing project costs.

Lack of leadership, ownership, and collaboration

Another obstacle to managing and using groundwater data in low-resource settings was the need for more leadership from government institutions and national bodies. Given the transboundary nature of groundwater resources, governments need to manage resources and collect, analyze, and store groundwater data. However, this does not occur for several reasons, including a shortage of skilled human capital within government institutions responsible for managing groundwater data, insufficient funding to maintain groundwater data collection systems, and a lack of regulatory frameworks to guide government institutions' roles in groundwater management.

Participants highlighted the significant challenge posed by limited collaboration among various stakeholders in groundwater data management. They provided examples of situations where different stakeholders repeatedly collect data on the same groundwater phenomenon due to inadequate guidance on existing data gaps. In low-resource settings, development partners may have different programmatic agendas and receive funding from other partners, hindering collaboration in collecting, analyzing, and storing groundwater data. Most development programs have short timelines, which limits the possibility of instituting effective collaboration mechanisms. These programs should be incentivized or mandated to share data, exacerbating the issue. Collaboration around the management and use of groundwater is challenging due to the varying ways practitioners consume information. For example, policy and government practitioners may need help to effectively collaborate with researchers and academics because of differences in how research findings are presented for policy purposes. An unwillingness to share groundwater data could further hinder collaboration among all stakeholders. This practice can make it challenging to access the data. Development partners and researchers may not freely share groundwater data collected during program implementation, which hampers collaboration.

Governments require more resources to maintain mechanisms for collecting groundwater data, data repositories, and data-sharing dashboards. In a scoping review of its member state groundwater management practices (Braune & Xu 2008), the Southern African Development Community (SADC) found that funding commitments demonstrated low prioritization of groundwater management, especially for 'monitoring, exploration, and data gathering'. One reason is the African states' dependence on external funding for development and the lack of hydrogeological monitoring in donor-driven water program design. Lack of consolidated groundwater data and understanding in many Asian countries have similarly limited the governments' prioritization of groundwater management in establishing policy and funding (Schwartz *et al.* 2020). This lack of leadership and funding perpetuates challenges. The lack of standards and regulations for managing groundwater data leads to the production of low-quality data. Additionally, there is a lack of readily accessible and affordable groundwater data and minimal collaboration on its collection and use.

Integrating data from various technologies (sensors, etc.) makes it easier to collect longitudinal data, but it has limitations

The DRIP technology has enabled low-cost monitoring of borehole systems and enhanced drought preparedness through the forecasting capability introduced using sensors, satellite data, and models driven by data science. However, many challenges have had to be overcome to realize the level of success that has been reported to date. The northern Kenya region is prone to insecurity from inter-community conflicts over grazing land and water points, exacerbated by climate change impacts. Technology failures have been reported where sensor security was compromised through vandalism and theft. Whereas these instances were more prevalent at the beginning of the intervention, considerable effort was put into community sensitization, trust-building, and ensuring transparency between the implementers and the beneficiaries. This intervention almost eliminated the risk to the sensors with increased ownership by the communities. DRIP has reported fewer cases of stolen sensor gateways, resulting in continuous monitoring of the borehole systems.

Sensors that send data to servers over the cellular network are more common than those that use satellite connections. However, cellular connectivity in remote northern Kenya is intermittent or completely unavailable, making it difficult for these off-grid regions to collect and send data remotely. The remoteness of program implementation regions can hinder realizing development progress. The DRIP intervention faced these challenges initially when all the sensors relied on a cellular connection, making it extremely difficult to send near real-time data to users. More recent advances have resulted in new generation sensor technology that connects these gateways to satellites, thus eliminating cellular coverage obstacles. While this has revolutionized data collection in such regions, it comes at an added cost that presents new challenges in resource-poor contexts. Different sensors have different mechanisms for measuring or estimating the variable of interest. For instance, DRIP sensors use electrical current as a proxy for use statistics or runtime. This method of *in situ* abstraction measurement has been demonstrated to have various levels of effectiveness. However, these sensors are prone to inaccuracies from factors including pump age and type, power supply, aquifer medium, and satellite connectivity (Holland *et al.* 2022). The latter is exposed to weather events such as heavy rainfall, which can weaken the signals from *in situ* sensors, thus compromising data quality. As such, technologies such as DRIP require regular calibration and validation with alternative but less infrequent measurements, such as those conducted by water service departments.

The solutions that groundwater data collection and analysis point to are not always feasible on the ground

Improving groundwater data access equality, developing leadership in the sector, and improving sensor technologies' reliability will enhance WaSH practitioners' ability to make informed decisions. However, side event participants identified barriers that may arise even as this data becomes more available and integrated. First, practitioners discussed a challenge in balancing responsible groundwater management with community concerns and preferences. For example, rainwater-dependent water sources and protected springs may be practical options for expanding access without increasing groundwater extraction in some settings. However, these sources can be unreliable across seasons (Yu *et al.* 2023) and face water quality issues (Haruna *et al.* 2005; Meera & Ahammed 2006), potentially making them less appealing to users.

Participants identified direct monitoring as a source of groundwater data for decision-making. However, one practitioner pointed out that their current methods of opening the well to measure static water level required shock chlorination following every groundwater monitoring visit. This makes the water source undrinkable for the community for at least 24 h. Separate monitoring wells and improved technologies such as depth sensors and the Pocket Dipper (GWR n.d.) could reduce the need to shock chlorinate community wells during monitoring, but it comes at an increased cost to the monitoring organization.

Recommendations

Sustainable groundwater management will require increased investment from both governments and implementing organizations. We recommend that all WaSH funders include groundwater monitoring requirements in their funding packages and dedicate resources to these activities. Funding should encompass capacity-building for local governments and implementing partners, enabling them to collect and analyze data, an effort often impeded by a shortage of hydrogeological expertise globally. WaSH practitioners should seek out more training to understand groundwater resources. Although some hydrogeologists work in the WaSH field, greater collaboration between these groups is needed. In settings with limited resources, capacity-building can prioritize open-source software suitable for integrating locally collected data. Implementers with existing water source monitoring programs have an opportunity to provide longitudinal data with minimal additional cost. Data collected through ongoing monitoring programs would help provide regularly updated datasets instead of one-time static datasets.

Organizations engaged in regular functionality or water quality monitoring should strive to incorporate groundwater monitoring to support IWRM. Groundwater monitoring and management should be prioritized and invested in, as the WaSH sector has acknowledged the need to improve the long-term functionality of point sources and has begun to invest in post-construction monitoring, operation, and maintenance. More recently, funding from the carbon markets for WASH programs has gained traction. These funding sources have predominantly concentrated on water treatment, but an expanded portfolio now includes water system functionality linked to water treatment. These new frontiers could provide the much-needed funding to support data collection for groundwater infrastructure functionality.

Governments must eventually take the lead in collecting, analyzing, and storing groundwater data, especially coordinating data collection and collaboration among local stakeholders. Governments should enact standards and regulations for managing groundwater data to ensure that data collected by stakeholders is high quality and usable. Improved groundwater policy and internal capacity will enable governments to protect their valuable natural resources and current and future economic development through productive groundwater use. Additionally, governments could leverage consolidated groundwater data for funding and advocacy purposes on a larger scale by identifying where better financial and technical support is needed for those managing water resources on the ground. Thus, groundwater data can be turned into sustainable funding for groundwater management.

Even with expanded funding for groundwater management, consistent monitoring, and government leadership in place, the WaSH sector would benefit from *a global groundwater monitoring data repository*. Currently, these professionals share their data through siloed databases, apps, and platforms, if they are sharing data at all. A global repository would represent a single location where actors across sectors and geographies could easily upload and access groundwater data.

The first step in establishing a global database is to train all users of the platform in basic groundwater terminology and best practices to ensure that data is collected, shared, and used based on consistent principles. Other fields, such as environmental health, have established communities of practice that help actors from different fields harmonize language, terminology, and data collection (e.g., indicators) (Holmgren *et al.* 2021; Holmgren *et al.* 2023). For WaSH practitioners to effectively contribute to and use the database, capacity-building, and intersectoral collaboration between WaSH and hydrogeology users will be key.

Temporal data (such as static water levels) and fundamental properties of groundwater systems (such as geology, permeability, and transmissivity) should all be included in a global database. Both types of data are needed to model and manage groundwater. Data should be provided in a raw format, such as a spreadsheet, that does not require specialized software (such as ArcGIS, as opposed to QGIS, which is free to use). This database should also allow for integrating data from different technologies, incorporating available field monitoring data, sensor technology outputs, remote sensing information, and more. Ideally, this database would document data collection methodology for quality control purposes.

Strategic long-term planning could be improved if widely used tools such as mWater combined groundwater data from such a database with other datasets (e.g., population, point sources). In parts of Bangladesh like Matlab, groundwater quality is extensively monitored regarding its relationship to *E. coli* and arsenic in deep and shallow tubewells and human health. Human health is monitored by ongoing health survey field research by the International Centre for Diarrheal Disease Research, Bangladesh (icddr,b), which has an extensive Health and Demographic Surveillance System (HDSS) that collects health information and vital demographic events from each household every month. The monitoring program has been in operation for decades. While the research and surveillance are more about water quality parameters such as arsenic and *E. coli* concerning human health, the collected data may be another example that can be linked to other such groundwater studies in Bangladesh (Masood *et al.* 2022; Parvin *et al.* 2022).

The database should be designed to consolidate groundwater data globally, to reach people working in as many geographies as possible, and to integrate data on transboundary aquifers. Still, the data would need to be aggregated locally, where data availability is critical to implementation decisions. The platform could facilitate collaboration by connecting data producers with users; for example, researchers could help implementers analyze and interpret data, and groundwater experts could summarize data and make recommendations to policymakers. Creating regional working groups could be one approach to fostering better collaboration. A centralized, publicly accessible database with information about groundwater availability, quality, and use would allow all actors, including governments, NGOs, and private entities, to make more informed decisions about groundwater use while allowing oversight bodies to protect groundwater resources.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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