PLOS Water

OPINION

Groundwater must be fully integrated into WASH programmes to make them climate resilient

Donald JC Robertson[1]*, Donald John MacAllister[2], Seifu Kebede Gurmessa[3], Jay Matta[4], Alan MacDonald[2], Catherine McManus[5,6], Tracy Morse[1], Aditi Mukherji[7], Muthi Nhlema[8]

1 Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, United Kingdom, **2** British Geological Survey, Edinburgh, United Kingdom, **3** School of Engineering, University of Kwazulu-Natal, Durban, South Africa, **4** Sustainable WASH Innovation Hub, UNICEF, Copenhagen, Denmark, **5** Engineering Department, Boston College, Chestnut Hill, Massachusetts, United States of America, **6** The Water Project, Concord, New Hampshire, United States of America, **7** Consultative Group on International Agricultural Research (CGIAR), Nairobi, Kenya, **8** BASEflow, Blantyre, Malawi

* donald.j.robertson@strath.ac.uk

OPEN ACCESS

Citation: Robertson DJ, MacAllister DJ, Gurmessa SK, Matta J, MacDonald A, McManus C, et al. (2025) Groundwater must be fully integrated into WASH programmes to make them climate resilient. PLOS Water 4(7): e0000404. https://doi.org/10.1371/journal.pwat.0000404

Editor: Guillaume Wright, PLOS: Public Library of Science, UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

Published: July 14, 2025

Funding: The author(s) received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

Groundwater is a critical source of freshwater that provides nearly half of global drinking water. Its comparative resilience to weather and climatic extremes, particularly drought, makes it essential to water security across agricultural, industrial, and ecological systems around the world [1–4].

In the Water, Sanitation and Hygiene (WASH) sector, groundwater is the predominant source of water for WASH services, especially in rural and low, middle-income settings (LMICs). Its prominence is driven, in part, by its widespread distribution and general resilience [5]. Yet, groundwater is not only a source for WASH services but impacted by them, both from contamination and overexploitation, highlighting a complex interdependent relationship. However, despite groundwater's fundamental importance, understanding and accounting for groundwater has long been an 'invisible' component in WASH programming and wider development planning – sidelined as a water resources issue instead of being core to ensuring sustainable service delivery [1,3,6].

As the WASH sector prioritizes climate resilience, this disconnect— as we noted in discussions at the 2024 UNC Water & Health Conference - is increasingly important to address. A recent, and welcomed, definition of climate-resilient WASH services [7] highlights the need for systems that can anticipate, respond to, cope with, and recover from climate-related events. Yet how can we ensure these goals are met if the underlying water resource for WASH services is poorly understood, not accounted for, and inconsistently managed? We argue that without integration – not just coordination - of groundwater into WASH programming, the climate-resilient WASH vision risks being aspirational rather than achievable.

Groundwater as integral to climate-resilient WASH

Groundwater's inter annual storage provides a resilient buffer against climatic extremes, often with lower treatment needs than surface water [2,8]. This, combined with groundwater frequently being the only feasible and affordable option for expanding water access, particularly in rural and underserved areas, makes it both an attractive and climate resilient source of water supply for WASH services [1]. Indeed, groundwater supplied infrastructure, such as handpumps, community standpipes and domestic taps, are common in WASH programmes in LMICs.

Beyond being a water source for WASH services, groundwater is also vulnerable to contamination. Poorly constructed or managed sanitation systems, especially in areas with shallow or unprotected aquifers, can impact groundwater quality, undermining safely managed service delivery and public health [9]. Accounting for groundwater is therefore an already critical, yet undervalued, component in planning and delivery of WASH services.

With increasing climate uncertainty, WASH reliance on groundwater is likely to grow, with groundwater being critical to buffering (but not eliminating) risks to water quality and availability when compared to surface water [9]. Yet, while dependence is increasing, the sustained availability and quality of groundwater is not guaranteed – its sustainability sits at a complex intersection of climate change, evolving water demands and local hydrogeological variability.

The risks and opportunities of using groundwater for WASH services

Understanding groundwater systems is complex, requiring long-term studies, management and planning [2,10,11]. While recent research has raised concerns over rates of global groundwater depletion and its consequences [12,13], including on WASH services, the global picture is not uniform. In some regions, particularly in sub-Saharan Africa, there are untapped groundwater resources that offer opportunities to support climate resilient development [14,15]. In contrast, over-abstraction in India, for example, has led to major challenges with both water quality and quantity [14]. Further, examples from the Bangkok basin and East Salt River basin show that good groundwater management can lead to improvement and recovery from periods of water stress [15]. Groundwater is also strategically valuable for responding to and recovering from climate shocks and humanitarian disasters [5,6].

Determining whether groundwater development presents a risk or an opportunity depends on our ability to understand localised groundwater complexities and their climate feedbacks [2]. To support this determination, groundwater assessments which evaluate storage, recharge, abstraction, and quality are necessary. Conducting these assessments depends on access to groundwater data and the appropriate monitoring systems to capture that data. However, both data and monitoring networks are scarce, especially in LMICs. Financial constraints, technical capacity availability, and fragmented governance frameworks further exacerbate the data scarcity challenge. As a result, in many contexts there is often limited groundwater expertise or knowledge available and where it does exist, it is often under-resourced and overstretched. As such, WASH actors cannot assume effective groundwater management is in place to coordinate with. Instead, if resilience is the goal, WASH actors must be prepared to actively contribute to groundwater characterisation and management needs themselves.

From parallel sectors to integrated thinking

The need for more integrated groundwater-WASH programming is perhaps most acute in sub-Saharan Africa. Persistent failure and low functionality of groundwater supplied WASH infrastructure has long undercut services [16]. In recent years, technology developments, such as solar-powered water pumps, have rapidly expanded across the region, partly driven by Sustainable Development Goal 6 targets, and are commonly implemented as part of standard WASH programmes. However, installation is frequently outpacing the understanding of local groundwater systems and their ability to support the increased demand pressures. Concurrently, climate change and the increasing demand from industrial and agricultural water users, particularly for irrigation, are putting further pressure on groundwater resources [17].

Without groundwater assessments and the mechanisms for collecting monitoring data, there is a dual risk: either exacerbating water stress and undermining climate-resilience or underutilising a strategic resource that could enhance resilience. Similarly, without robust systems and support in place to monitor issues, for example geogenic or anthropogenic water quality contamination, WASH services are, and will remain, at continued risk.

Actions to promote groundwater conscious climate-resilient WASH

We recognise that the challenge of sustainable groundwater management requires attention beyond just WASH. Agricultural withdrawals, for example, typically far exceed those of WASH and the need to coordinate with these sectors is self-evident. However, it is the direct and immediate link between groundwater and resilient WASH services that should compel leadership and investment from within the WASH sector.

As such, groundwater must be recognised as integral to climate-resilient service delivery in WASH programming – and treated as such. The following offers suggested actions which we believe would enhance this recognition:

1. **Strengthen support for groundwater assessment and monitoring**: Groundwater assessments help identify the risk or opportunity balance for groundwater development. Actively incorporating support for groundwater monitoring and assessment initiatives as part of WASH programmes would make meaningful impact on groundwater data scarcity, especially in LMICs.
2. **Align governance and accountability structures**: Data-driven monitoring enables more transparent, equitable, and anticipatory resource management strategies [6]. WASH programmes can support this by aligning developments with national water resource strategies, sharing groundwater data from WASH interventions, e.g., submission of drilling reports to regulators, and supporting long-term accountability through compliance monitoring and partnerships with regulators and hydrogeological experts.
3. **Embed groundwater in resilience planning and metrics**: Where suitable groundwater management is missing, groundwater dependent WASH services cannot be considered climate resilient. Developing metrics that account for groundwater management structures - such as availability of local groundwater assessments or monitoring data - should be used to evaluate the resilience of WASH services.
4. **Direct Official Development Assistance and sovereign borrowing finance towards groundwater**: Achieving universal access to WASH, enshrined in SDG6, is estimated to require $114 billion USD annually until 2030 [18]. While that amount is a big ask in the current geopolitical climate, it is widely acknowledged that the cost of inaction to society is likely far higher [19]. Investment in groundwater knowledge and management must be seen in the same manner. Redirecting and prioritising some Official Development Assistance and sovereign borrowing to groundwater assessment, monitoring and capacity building could close critical data and knowledge gaps required for ensuring climate resilience. Exploring the role of other finance mechanisms, such as for ecosystem services, should also be explored.
5. **Design programmes to maximise co-benefits across sectors**: Groundwater management cannot be sidelined into water resource silos. While integrating groundwater into WASH thinking, actors must also work alongside agricultural,

industrial and other domestic users to coordinate abstraction, share data, and protect shared aquifers. Integrated management approaches, including with indigenous and local knowledge sources, must be explored and implemented to leverage co-benefits and cohesion across institutions and communities.

Climate change, population and economic change are placing increasing strain on WASH services, making groundwater increasingly critical for resilience. Yet for many regions, particularly in LMICs, groundwater remains poorly understood, inconsistently monitored and weakly governed. Without active integration of groundwater into WASH programming, we risk undermining or overlooking opportunities for building climate-resilience. If WASH is to achieve the aspiration of climate-resilient services, WASH actors must go beyond considering groundwater an interesting side issue. Demonstrating leadership and integrating groundwater into WASH planning, investment, and programming decisions is no longer optional, but essential.

Author contributions

Conceptualization: Donald John Charles Robertson, Donald John MacAllister, Seifu Kebede Gurmessa, Jay Matta, Alan MacDonald, Catherine McManus, Tracy Morse, Aditi Mukherji, Muthi Nhlema.

Writing – original draft: Donald John Charles Robertson, Donald John MacAllister.

Writing – review & editing: Donald John Charles Robertson, Donald John MacAllister, Seifu Kebede Gurmessa, Jay Matta, Alan MacDonald, Catherine McManus, Tracy Morse, Aditi Mukherji, Muthi Nhlema.

References

1. UN-Water. The United Nations World Water Development Report 2022: Groundwater: Making the invisible visible. Paris: UNESCO. 2022.
2. Taylor RG, Scanlon B, Döll P, Rodell M, van Beek R, Wada Y, et al. Ground water and climate change. Nature Clim Change. 2012;3(4):322–9. https://doi.org/10.1038/nclimate1744
3. Foster S, MacDonald A. The 'water security' dialogue: why it needs to be better informed about groundwater. Hydrogeol J. 2014;22(7):1489–92. https://doi.org/10.1007/s10040-014-1157-6
4. Caretta MA, Mukherji A, Arfanuzzaman M, Betts RA, Gelfan A, Hirabayashi Y, et al. Water. In: Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, et al. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press. 2022. pp. 551–712. https://doi.org/10.1017/9781009325844
5. MacAllister DJ, MacDonald AM, Kebede S, Godfrey S, Calow R. Comparative performance of rural water supplies during drought. Nat Commun. 2020;11(1):1099. https://doi.org/10.1038/s41467-020-14839-3 PMID: 32132535
6. Gregory A, Kelly E, Landa S, Muthike DM, Samo J, Lopez J, et al. Challenges and opportunities for enhancing groundwater data access and usability in low- and middle-income countries: insights and recommendations from WaSH researchers and practitioners. Journal of Water, Sanitation and Hygiene for Development. 2024;14(10):929–37. https://doi.org/10.2166/washdev.2024.066
7. Sanitation and Water for All. Definition of climate-resilient water sanitation and hygiene services. 2024 Nov. Available from: https://www.sanitationandwaterforall.org/impact/document-library
8. Lapworth DJ, Boving TB, Kreamer DK, Kebede S, Smedley PL. Groundwater quality: Global threats, opportunities and realising the potential of groundwater. Sci Total Environ. 2022;811:152471. https://doi.org/10.1016/j.scitotenv.2021.152471 PMID: 34915019
9. Mbae M, Hansen P, Way C, Mills F, Willetts J, Foster T, et al. Onsite sanitation systems and contamination of groundwater: A systematic review of the evidence for risk using the source-pathway-receptor model. PLOS Water. 2024;3(7):e0000167. https://doi.org/10.1371/journal.pwat.0000167
10. Kuang X, Liu J, Scanlon BR, Jiao JJ, Jasechko S, Lancia M, et al. The changing nature of groundwater in the global water cycle. Science. 2024;383(6686):eadf0630. https://doi.org/10.1126/science.adf0630 PMID: 38422130
11. Scanlon BR, Fakhreddine S, Rateb A, de Graaf I, Famiglietti J, Gleeson T, et al. Global water resources and the role of groundwater in a resilient water future. Nat Rev Earth Environ. 2023;4(2):87–101. https://doi.org/10.1038/s43017-022-00378-6
12. Jasechko S, Seybold H, Perrone D, Fan Y, Shamsudduha M, Taylor RG, et al. Rapid groundwater decline and some cases of recovery in aquifers globally. Nature. 2024;625(7996):715–21. https://doi.org/10.1038/s41586-023-06879-8 PMID: 38267682
13. Bierkens MFP, Wada Y. Non-renewable groundwater use and groundwater depletion: a review. Environ Res Lett. 2019;14(6):063002. https://doi.org/10.1088/1748-9326/ab1a5f

14. MacDonald AM, Bonsor HC, Ahmed KM, Burgess WG, Basharat M, Calow RC, Dixit A, Foster SS, Gopal K, Lapworth DJ, Lark RM. Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. Nature Geoscience. 2016 Oct;9(10):762–6. https://doi.org/10.1038/ngeo2791
15. MacAllister DJ. Groundwater decline is global but not universal. Nature. 2024;625(7996):668–70. https://doi.org/10.1038/d41586-024-00070-3 PMID: 38267676
16. MacAllister DJ, Nedaw D, Kebede S, Mkandawire T, Makuluni P, Shaba C, et al. Contribution of physical factors to handpump borehole functionality in Africa. Sci Total Environ. 2022;851(Pt 2):158343. https://doi.org/10.1016/j.scitotenv.2022.158343 PMID: 36041625
17. Siebert S, Burke J, Faures JM, Frenken K, Hoogeveen J, Döll P, et al. Groundwater use for irrigation – a global inventory. Hydrol Earth Syst Sci. 2010;14(10):1863–80. https://doi.org/10.5194/hess-14-1863-2010
18. UN-Water. The United Nations World Water Development Report 2024: Water for Prosperity and Peace. Paris: UNESCO. 2024.
19. Pories L, Fonseca C, Delmon V. Mobilising Finance for WASH: Getting the Foundations Right. Water. 2019;11(11):2425. https://doi.org/10.3390/w11112425