Ethiopia: Groundwater Dossier

Key recommendations

Government: National and Local

- Actively engage with the **AMCOW Pan-African Groundwater Program**
- **Continuous and strategic groundwater monitoring** is needed to build an understanding of groundwater recharge processes and patterns in different aquifer systems over the long-term, contributing to more effective, forward-looking and resilient groundwater management strategies
- Installation of **boreholes with handpumps can improve resilience to drought,** as they provide a more reliable water supply than springs or hand-dug-wells. In the Ethiopian highlands, communities who relied solely on springs, wells or rivers experienced severe water shortage in the El Niño 2015/2016 drought, with impacts on livelihoods, education and health.
- Groundwater stores are replenished episodically in response to extreme rainfall events. During wet periods, in favourable hydrogeological environments, focussed groundwater recharge can be enhanced to make full use of groundwater storage through **managed aquifer recharge (MAR)**.
- Accept that **handpump services will breakdown and design robust systems** that reduce the number of breakdowns per year and minimise the time it takes to repair a pump (downtime).
- Set **realistic targets for handpump functionality using metrics that provide information on long-term sustainability of the facility**, rather than simple functionality, and collect data accordingly.
- Require all agencies providing drinking water through handpumps to use **standard definitions and methods to measure functionality**. This will enable national measurement of progress towards the **SDG goal of ensuring that everyone has access to drinking water** by 2030.
- Analyse **handpump functionality data** to determine whether irreversible breakdown and abandonment is occurring early in handpump lifecycles, as this indicates problems in site selection, installation, and commissioning. These problems can be rectified through **better planning, improved contracting, and building of capacity of well-drillers.**
- Policy focusing on extending water supply coverage, at the expense of sustainable service provision, must be revisited.
- **Overlapping roles and responsibilities** for the management and delivery of water supplies need to be clarified. One avenue for this could be **to legalise WASHCOs** with clear roles and responsibilities to improve accountability.
- Decentralised delivery of water supply services must be matched with **adequate fiscal decentralisation** to ensure that districts have the financial resources needed to perform their role.
- **Districts need structured capacity support** to enable them to adequately support communities in managing and maintaining their water supply.
- Efforts to **calculate the full costs of reaching and sustaining universal water supply access** (using various service options) in the district must be undertaken and integrated into district plans. These must be complemented by efforts to identify and leverage additional funding sources to implement costed plans.

Commented [SF1]: Target Audiences

Government
MoWIE: Senior Technical Advisors
ONE WASH programme
MoAg: Senior Technical Advisors

Donor/Development Partners
DFID Country Office
UNICEF WASH team (country/regional)
World Bank
African Development Bank

iNGOs
Millennium Water Alliance

Private Sector

Civil society and national NGOs

- Inform and build on the 2018 National WASH Inventory (NWI) by supporting efforts for **data collection on functionality** and investments into **water resource mapping**. This will improve the **data available to Woreda and regional governments** to map resource availability and provide governments with a platform to track waterpoint functionality.
- Leverage drought events to **reframe the conversation around water service provision** by highlighting that sustaining water point functionality in climate stress depends on better monitoring, siting and maintenance during 'normal' years.

Private sector

- All agencies providing drinking water through handpumps should use **standard definitions and methods to measure functionality**.

International Development Cooperation and Aid agencies (iNGOs, UN organisations)

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Further research

Emerging research priorities from GroFutures research into groundwater recharge and resource availability for the future include further research into the widespread occurrence of episodic, focused recharge and the sustainability of small-holder irrigation from shallow groundwater replenished via ephemeral river flow. There are specific questions that need to be addressed around the scale and sustainability of local groundwater use, including consideration of use by whom and for what. Furthermore, the impact of water capture (for hydropower?) on downgradient water resources requires research and consideration in basin water management planning.

Commented [HP2]: GroFutures inputs welcome here

Modelling of the impacts of climate change on groundwater resources has demonstrated the importance of long-term groundwater monitoring records for model validation. Greatly increasing the spatial coverage of long-term groundwater monitoring across Africa is needed to support model validation and improve projections of climate impacts on water security. Investment in observation-driven research into ground and surface water resources is therefore needed, to support modelling and development of pathways for future water resource use, to inform national adaptation planning for the Water Sector.

For sustainable rural water services, further research needs include…

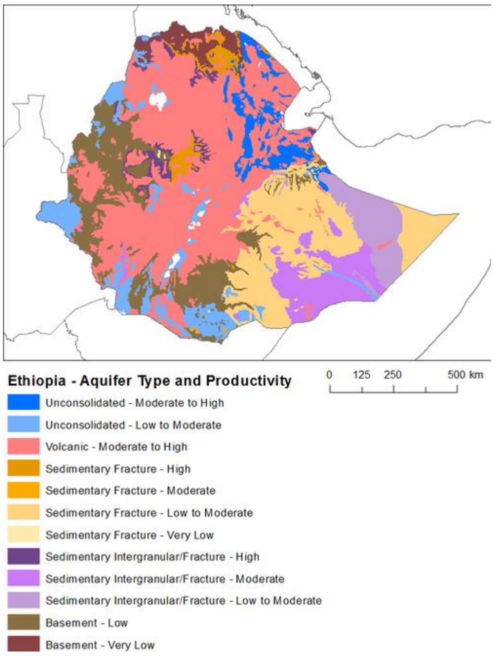
Commented [HP3]: Hidden Crisis inputs welcome here

Context: highlights from the Africa Groundwater Atlas

http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Ethiopia

Groundwater Quantity

- Recharge over Ethiopia is extremely variable. It varies from nearly 0 to 300 mm/yr. Nearly 60% of aquifers receive indirect recharge from floods, mountain runoff, as well as fast recharge from high rainfall events. Diffuse recharge is limited to the plateau region, which accounts for around 30% of the country.
- Annual renewable groundwater resources are estimated at around 36,000 million cubic metres (36 billion cubic metres) , with estimates of total groundwater storage varying from 1,000 to 10,000 billion m³.



Groundwater Quality

- An estimated 30% of groundwater storage is not available for direct use because of high salinity and/or high fluoride, which have health risks.

Groundwater Use

- Groundwater provides more than 90% of the water used for domestic and industrial supply in Ethiopia, but a very small proportion of water used for irrigation, which mostly comes from surface water.
- Groundwater-Surface Water Interaction: There are a number of groundwater dependent surface waters, including wetlands and lakes.

Key activities and findings from UPGro research in Ethiopia

General UPGro findings with relevance to Ethiopia

Climate Resilience & Groundwater Resources	▶ Climate change may enhance groundwater recharge in arid and semi-arid areas, presenting opportunities for long-term management as part of national climate adaptation strategies. ▶ Across the West African Sahel, rainy seasons are projected to be later than historically, with fewer but more intense rainfall events. ▶ This may favour more focused groundwater recharge along watercourses. ▶ Observed groundwater levels have generally risen across the Sahel, despite declining rainfall, this "Sahelian Paradox" is thought to be due to changes in the land use and vegetation cover. UPGro research aligns with this view. ▶ Local hydrogeological understanding is required to define the sustainable yield of water points, particularly in weathered basement aquifers. ▶ Numerical groundwater models can be used to assess the sustainability of different groundwater scenarios to inform groundwater management and planning. ▶ Bacteriological contamination of groundwater is likely to be a significant barrier to achieving safely managed water services under SDG6, but this can be tackled by improved construction practices.
Groundwater and Poverty	▶ Communities are routinely under high water stress due to social pressures (e.g. funerals, cultural events) and environmental pressures (e.g. dry periods). These pressures cascade with routine sharing of water points. ▶ Women are more at risk of water scarcity due to gender roles and gender task allocation.
Sustainable Rural Water Services	▶ New methods for defining and measuring water point functionality are required to adequately monitor progress towards SDG6 for safely managed water services. ▶ Affordable maintenance and repair are one of the main predictors of borehole functionality. This highlights the need for effective management models to address poor functionality.
Urban Water Security	▶ In urban areas experiencing rapid population growth, increased demand for water is likely to have a much more significant impact on groundwater than climate change. ▶ Groundwater can only gain a role as a strategic urban resource where an integrated approach to urban water management and governance acknowledges the importance of all available resources. Conjunctive use, managed aquifer recharge, and suitable treatment

measures are vital to make groundwater a strategic resource on the urban agenda.

- Participatory, community-led approaches, such as Transition Management, can provide new and collaborative ways of using and managing urban groundwater.

Agriculture and livelihoods

- Access to groundwater is associated with improved agricultural production, reduced agricultural risk, and improved livelihoods.
- Knowledge sharing approaches, such as Rainwatch and Farmer Radio, can be used to increase resilience by communicating farming practices that align with sustainable intensification, climate and groundwater forecasts with farmers.

Ethiopia-specific activities and findings

Climate Resilience & Groundwater Resources

- In arid and some semi-arid environments, groundwater stores are replenished episodically in response to extreme rainfall events. Such events may become more common under climate change and are often related to predictable climate phenomena such as El Nino.
- During wet periods, in favourable hydrogeological environments, focussed recharge can be enhanced to make full use of groundwater storage through managed aquifer recharge (MAR).
- 6 groundwater development pathways were described and impacts on the water table quantified (see case study). Consultation with groundwater users prioritised a pathway of medium-scale abstraction and multiple uses, managed centrally by a municipal or community-based authority.
- In the Dangila woreda in the highlands, shallow groundwater and surface water remain available into the dry season, when well yields of 1 L/s can be achieved.
- In the Ethiopian highlands, boreholes with handpumps are a more reliable water supply during the dry season than springs and hand-dug-wells. Communities who relied solely on springs, wells or rivers experienced severe water shortage in the El Niño 2015/2016 drought, with impacts on livelihoods, education and health. Resilience to drought can be improved by installation of boreholes with handpumps.
- In the Ethiopian Central Rift Valley, high fluoride concentrations in groundwater are detrimental to health. Community-level defluorination schemes are only appropriate for isolated communities which cannot be connected to the large water supply schemes.
- Road building affects water flow. Construction of ponds, culverts and channels to farmland can help manage water from roads to improve groundwater supply, soil moisture, productivity of farmland and prevent flooding.

Sustainable Rural Water Services

- Communities are routinely under high water stress with diaries showing both regular pressures from funerals, cultural events and dry periods.
- Pressures on water points often cascade with routine sharing of water points with neighbouring communities due to poor functionality.
- A 2016 survey of boreholes with handpumps covering 400 Woredas in the Ethiopian Highlands showed that 82% were working on the day of the survey. Only 28% of handpumps surveyed passed the design yield, reliability and water quality criteria.
- The main physical factors affecting handpump performance within the Ethiopian Highlands are the relatively deep depth to groundwater and the poor condition of handpump components.
- Reducing the number of handpump breakdowns and minimising the time it takes to repair them are vital to improve access to water services.
- Data collection and analysis on handpump functionality is essential for rapid repair. Metrics should focus on long-term sustainability of the facility, rather than simple functionality at the time of measurement.
- Handpump functionality datasets should include information on water point age, frequency of breakdown, and length of downtimes, as well as differentiating 1) water yield and quality limitations, including seasonality constraints 2) limitations in well siting, design, and installation, and 3) limitations of handpump maintenance and financing arrangements.
- The major barriers to more sustainable water services in Ethiopia were identified through political economy analysis and a District Water Supply Sustainability analysis. Major challenges included: patchy information management systems, insufficient investments in human capacity and local management arrangements, overlapping roles and responsibilities, a slow-moving supply chain for spare parts and a lack of accountability to water users.

Agriculture and livelihoods

- A survey of 399 households in the Upper Awash Basin, Ethiopia showed that groundwater-fed irrigation was practised by 41% of people in Upper Awash.
- The survey also showed that access to groundwater was associated with improved agricultural production, poverty reduction, reduced agricultural risk, and increased income of farm households who have adopted groundwater irrigation as compared to their counterfactual households.

Case Studies

Six pathways identified for sustainable groundwater futures in Africa

https://steps-centre.org/blog/six-pathways-identified-for-sustainable-groundwater-futures-in-africa/

The ultimate aim of the GroFutures project is to generate new evidence and relevant policy insights to open up new pathways towards more sustainable and 'pro-poor' groundwater futures in the wider regions around three 'basin observatories': the Great Ruaha in Tanzania, the Upper Awash in Ethiopia, and the Iullummeden in Niger and Nigeria. A key aim to achieving this has been to identify a range of existing, emerging and potential 'groundwater development pathways' in each basin.

Six groundwater development pathways were conceptualised by the GroFutures Social Science Team. These pathways describe 'stylised' ways of using groundwater, and represent broader trends found across the three basin observatories. To analyse the longer-term sustainability of groundwater in each basin, the GroFutures Physical Science Team 'stress tested' or quantified the impacts of the groundwater development pathways, together with the impacts of climate and land-use change, on groundwater recharge and storage in each basin. A key assumption is that these pathways may co-exist over time and meet the needs of different users. However, there may be cases where there are serious trade-offs between them, leading to positive and negative impacts for different water users and for the environment.

Summaries of the six pathways and their hydrological impacts for the Upper Awash Basin, Ethiopia are outlined below:

Pathway	Groundwater usage	Occurring in Ethiopia?	Impact on water table
1	Small-scale, self-supply for multiple uses	Yes	Minimal: groundwater levels fall less than 2 metres over the entire study area.
2	Small-scale private supply for smallholder intensified agriculture	This pathway is emerging in Ethiopia.	Moderate: groundwater levels decline by 2 to 3 metres over approximately 25 % of the study area.
3	Medium-scale municipal supply for multiple uses	Yes	Moderate: groundwater levels decline less than 3 metres over the entire study area.
4	Medium-scale private supply for commercial agriculture	Yes	Moderate to substantial: groundwater levels fall by 3 to 5 metres over approximately 28 % of the study area.
5	Medium-scale private supply for livestock husbandry	This pathway is not yet evident in Ethiopia but is suggested in some policy approaches.	Moderate to substantial: groundwater levels fall by 3 to 5 metres over approximately 28 % of the study area.
6	Large-scale private supply for commercial agriculture	Yes	Substantial to very substantial: groundwater levels fall more than 5 metres over approximately 27 % of the study area.

Measuring progress on water point functionality requires standards definitions and assessments

http://nora.nerc.ac.uk/id/eprint/523090/

Currently, there is no universally adopted definition of water point functionality, or what constitutes a functioning water point. Assessing progress towards the SDGs requires agreed definitions and standard assessment approaches.

The Hidden Crisis project developed a set of common definitions and methods for assessing water point functionality and performance. A tiered approach to defining and measuring functionality was found to be useful to examine functionality for different scales and purposes. This approach has been applied in functionality surveys across Ethiopia, Uganda and Malawi, as part of Hidden Crisis research.

The guidelines for assessing water point functionality are summarised as:

1. Functionality should be measured against explicitly stated standards of the performance of the water point, so that functionality data from different regions and surveys can be compared.
2. It should be measured separately from the users' experience of the service provided.
3. Functionality assessments should be tiered, to ensure a minimum top-tier assessment can be completed by all surveys, but allowing for further, more detailed, tiers of assessments to be conducted at local levels.
4. A distinction should be made between surveying functionality as a snapshot (e.g. for national metrics) and surveying individual water point performance (where a temporal aspect of the water point performance is included in a rapid assessment).

The tiered approach to defining water point functionality involves 4 levels:

1. Binary Functionality – is the water point working and delivering some water (yes/no)
2. Functionality: yield snapshot – does the water point work and provide sufficient yield (10 L/min) on the day of the survey
3. Functionality: reliable yield – does the water point provide sufficient yield (10 L/min) on the day of survey, is it reliable (<30 days downtime in last year) or abandoned (not worked in past year)?
4. Reliable yield and water quality - as 3 above, and also passes WHO guidelines for water quality.

Application of these definitions of functionality in the field have shown that the measure of *reliable yield* gives much more useful information about the service level of the water point than a binary assessment, and generally reduces functionality rates by 50%.

For full details of the definitions and methods developed, please see the technical briefing which has been published here: http://nora.nerc.ac.uk/id/eprint/523090/.

Adaptive management of shallow groundwater at the local community level in Dangila woreda, Ethiopia

https://upgro.files.wordpress.com/2014/03/amgraf-preliminary-assessment-of-governance.pdf

Participatory enquiry at pilot study sites.

The AMGRAF UPGro catalyst project aimed to integrate information from global remote sensing products and hydrological modelling with local indigenous knowledge and appropriate social and governance systems to support local adaptive management of groundwater resources in Ethiopia.

Assessments of formal and informal institutions for resource management were based around the sites selected for the technical evaluation in Amhara region. Dangila woreda comprises 27 rural kebeles; three were selected for detailed study on the basis of: (i) access to market and road as proxy of market orientation which is necessary for adoption of groundwater irrigation, (ii) experience in small scale irrigation, (iii) potential of shallow groundwater and experience in evidence of groundwater use for small-scale irrigation. The selected kebeles are: Kwakurta, Gult and Dengesheta.

Using informal participatory enquiry within these sites, the emphasis was on understanding the role of groundwater in the livelihood system and gaining insights into local knowledge of groundwater. The entry point in each kebele was to undertake participatory mapping exercises with groups of women and men. After establishing interest in gaining improved understanding, the next step was to test feasibility of participatory assessment of the resource through monitoring groundwater levels, rainfall and streamflow.

The pilot study and associated stakeholder consultations in Ethiopia have confirmed that local level participatory management of shallow groundwater is both necessary and feasible provided that appropriate tools and governance arrangements can be devised.

In the absence of any prior experience with suitable groundwater governance arrangements, it is apparent that the best entry point for local level participatory research will be to build upon other experience with (a) community-based catchment management and (b) farmer-managed irrigation.

More information

Type	Organisation	Contacts
Ministries and authorities	Ministry of Water, Irrigation and Energy (MoWIE) Ministry of Agriculture Geological Survey of Ethiopia	
UPGro projects in Ethiopia	Groundwater Futures in Sub-Saharan Africa (GroFutures)	Prof. Richard Taylor (UCL) http://grofutures.org/
	Hidden Crisis: Unravelling past failures for future success in Rural Water Supply	Prof. Alan MacDonald (BGS) https://upgro-hidden-crisis.org/
	AMGRAF: Adaptive management of groundwater in Africa	John Gowing (Newcastle University) https://upgro.org/catalyst-projects/amgraf/
	Improving access to safe drinking water prospection for low-fluoride sources of groundwater	Dr Pauline Smedley (BGS) https://upgro.org/catalyst-projects/prospection-for-low-fluoride-sources-of-groundwater/
	Roads for Recharge	Frank van Steenbergen (MetaMeta Research) www.roadsforwater.org
UPGro researchers in-country	Addis Ababa University	Dr Tenalem Tegaye, Ass. Prof. Yohannes Aberra Ayele (GroFutures) Dr Seifu Kebede (Hidden Crisis, Low-fluoride sources of groundwater)
	Mekelle University	Kifle Woldearegay Woldemariam (Roads for Recharge)
	WaterAid Ethiopia	
	Geological Survey of Ethiopia	Mr Demis Alamirew Ayenew (AMGRAF)
Online tools and databases	Africa Groundwater Atlas	earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Ethiopia
	Groundwater Assessment Platform	www.gapmaps.org/gap.protected/
	Water Point Data Exchange	www.waterpointdata.org/
	IGRAC Global Groundwater Information Systems	www.un-igrac.org/global-groundwater-information-system-ggis
	UNHCR WASH Data Portal	wash.unhcr.org/wash-gis-portal/

UPGro published work relating to Ethiopia

https://upgro.org/publications-papers

1. Rural water supply in Ethiopia A political economy analysis, F. Pichon (2019) ODI Report https://upgrohiddencrisisdotorg.files.wordpress.com/2019/08/pea_odi_ethiopia.pdf
2. Groundwater and resilience to drought in the Ethiopian Highlands, M. MacDonald, R. A Bell, S. Kebede, T. Azagegn, Y. Tadesse, F. Pichon, M. Young, A. McKenzie, D. J. Lapworth, E. Black and R. C. Calow (2019) *Environmental Research Letters* https://doi.org/10.1088/1748-9326/ab282f
3. Groundwater and Poverty Groundwater and poverty in sub-Saharan Africa – a short investigation highlighting outstanding knowledge gap , R. C. Carter et al. UPGro Working Paper (June 2017)
4. Kebede, S.; MacDonald, A.M.; Bonsor, H.C; Dessie, N.; Yehualaeshet, T.; Wolde, G.; Wilson, P.; Whaley, L.; Lark, R.M.. 2017. UPGro Hidden Crisis Research Consortium : unravelling past failures for future success in Rural Water Supply. Survey 1 Results, Country Report Ethiopia. Nottingham, UK, British Geological Survey, 17pp. (OR/17/024). http://nora.nerc.ac.uk/id/eprint/516998/
5. Kebede, S.; Fallas, H.C.; MacAllister, D.J.; Dessie, N.; Tayitu, Y.; Kefale, Z.; Wolde, G.; Whaley, L.; Banks, E.; Casey, V.; MacDonald, A.M.. 2019 Physical factors contributing to rural water supply functionality performance in Ethiopia. Nottingham, UK, British Geological Survey, 24pp. (OR/19/055)
6. Girma Aboma (2018). District Water Supply Sustainability Assessment, Final Country Report Ethiopia. UPGro Hidden Crisis.
7. Report on the hydrogeological investigation in Dangila woreda, Ethiopia, Newcastle University
8. Preliminary assessment of policies, regulations and institutions required for management of shallow groundwater at local community level in Dangila woreda, Ethiopia, Newcastle University
9. Multifunctional Roads: The Potential Effects of Combined Roads and Water Harvesting Infrastructure on Livelihoods and Poverty in Ethiopia, Demenge, J., Rossella Alba, R,. Welle, K., Manjur, K., Addisu, A., Mehta, L.,Woldearegay K. (2015) doi: 10.1177/0974930615609482 Journal of Infrastructure Development December 2015 vol. 7 no. 2 165-180
10. How to Make Water Wise Roads Steenbergen, F. van, K. Woldearegay, H.M. van Beusekom, D. Garcia Landarte, and M. Al-Abyadh (2014) IFAD, Rome
11. Comparing Defluoridation and Safe Sourcing For Fluorosis Mitigation in the Ethiopian Central Rift Valley Datturi, van Steenbergen, van Beusekom, Kebede (2015) Fluoride 48(4)281-304, October-December 2015
12. Chronic Alcohol Consumption and the Development of Skeletal Fluorosis in a Fluoride Endemic Area of the Ethiopian Rift Valley Tekle-Haimanot R. and G. Haile (2014), "," Journal of Water Resource and Protection, Vol. 6 No. 2, 2014, pp. 149-155. doi: 10.4236/jwarp.2014.62020.y
13. Improving access to safe drinking water: Prospection for low-fluoride sources." Brief report presenting main findings – Addis Ababa, Meta Meta / Addis Ababa University (2014) August 2014
14. Berehanu, B., Ayenew, T. and Azagegn, T., 2017. Challenges of groundwater flow model calibration using MODFLOW in Ethiopia: with particular emphasis to the Upper Awash River Basin. Journal of Geoscience and Environment Protection, 5, 50-66. doi:10.4236/gep.2017.53005.
15. Thompson, J., Bellwood-Howard, I., Gebregziabher, G., Shamsudduha, M., Taylor, R., Kilave, D., Tarimo, A. and Kashaigili, J., 2019. Six pathways identified for Sustainable Groundwater Futures in Africa. GroFutures, STEPS Centre, University of Sussex, Brighton.
16. Shamsudduha, M. and Taylor, R.G., 2019. Groundwater storage dynamics in the world's large aquifer systems from GRACE: uncertainty and role of extreme precipitation. Earth System Dynamics Discussion, doi:10.5194/esd-2019-43.
17. Cuthbert, M.O., Taylor, R.G., Favreau, G., Todd, M.C., Shamsudduha, M., Villholth, K.G., MacDonald, A.M., Scanlon, B.R., Kotchoni, D.O.V., Vouillamoz, J.-M., Lawson, F.M.A., Adjomayi, P.A., Kashaigili, J., Seddon, D., Sorensen, J.P.R., Ebrahim, G.Y., Owor, M., Nyenje, P.M., Nazoumou, Y., Goni, I., Ousmane, B.I., Sibanda, T., Ascott, M.J., Macdonald, D.M.J., Agyekum, W., Koussoubé, Y., Wanke, H., Kim, H., Wada, Y., Lo, M.-H., Oki, T., Kukuric, N., 2019. Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. Nature, 572, 230-234.
18. Kolusu, S.R., Shamsudduha, M., Todd, M.C., Taylor, R.G., Seddon, D., Kashaigili, J.J., Ebrahim, G.Y., Cuthbert, M.O., Sorensen, J.P.R., Villholth, K.G., MacDonald, A.M. and MacLeod, D.A., 2019. The El Niño event of 2015–16: Climate anomalies and their impact on groundwater resources in East and Southern Africa. Hydrology and Earth System Science, 23, 1751-1762.
19. Taylor, R.G., Favreau, G., Scanlon, B.R. and Villholth, K.G., 2019. Topical Collection: Determining groundwater sustainability from long-term piezometry in Sub-Saharan Africa. Hydrogeology Journal, 27(2), 443-446.
20. Maurice, L., Taylor, R.G., Tindimugaya, C., MacDonald, A.M., Johnson, P., Kaponda, A., Owor, M., Sanga, H., Bonsor, H.C., Darling, W.G., and Gooddy, D., 2018. Characteristics of high-intensity

groundwater abstractions from weathered crystalline bedrock aquifers in East Africa. Hydrogeology Journal, doi:10.1007/s10040-018-1836-9.

21. Bonsor, H.C., Shamsudduha, M., Marchmont, B., MacDonald, A.M., and Taylor, R.G., 2018. Seasonal and decadal groundwater changes in African sedimentary aquifers estimated using GRACE products and LSMs. Remote Sensing, 10, 904, doi:10.3390/rs10060904.
22. Damkjaer, S. and Taylor, R., 2017. The measurement of water scarcity: Defining a meaningful indicator. Ambio, doi:10.1007/s13280-017-0912-z.
23. Zeitoun, M., Lankford, B., Krueger, T., Forsyth, T., Carter, R., Hoekstra, A.Y., Taylor, R.G., Varish, O., Cleaver, F., Boelens, R., Swatuk, L., Tickner, D., Scott, C.A., Mirumachi, N., and Matthews, N., 2016. Reductionist and integrative research approaches to complex water security policy challenges. Global Environmental Change, Vol. 39, 143-154.
24. Jasechko, S. and Taylor, R.G., 2015. Intensive rainfall recharges tropical groundwaters. Environmental Research Letters, 10, 124015. ERL News article, 3 May 2016.
25. Taylor, R.G., 2014. When wells run dry. Nature, 516, 179-180.
26. Ibrahim, M., Favreau, G., Scanlon, B.R., Seidel, J.L., Coz, M., Demarty, J. and Cappelaere, B., 2014. Long-term increase in diffuse groundwater recharge following expansion of rainfed cultivation in the Sahel, West Africa. Hydrogeology Journal, 22(6), 1293-1305.
27. Taylor, R.G., Todd, M., Kongola, L., Nahozya, E., Maurice, L., Sanga, H. and MacDonald, A., 2013. Evidence of the dependence of groundwater resources on extreme rainfall in East Africa. Nature Climate Change, Vol. 3, 374-378. doi:10.1038/nclimate1731.
28. Richard C. Carter & Ian Ross (2016). Beyond 'functionality' of handpump-supplied rural water services in developing countries. Waterlines, 35(1), DOI: 10.3362/1756-3488.2016.008
29. UNC Water Institute WaSH Policy Research Digest Issue #3, March 2016. Detailed Review of a Recent Publication: Getting handpump functionality monitoring right can help ensure rural water supply sustainability.
30. Bonsor, H., MacDonald, AM., Casey, V., Carter, R., Wilson, P. 2018. The need for a standard approach to assessing the functionality of rural community water supplies. Hydrogeology Journal, 26; 2, 367-370. https://doi.org/10.1007/s10040-017-1711-0
31. Whaley, L., Cleaver., F. 2017. Can 'functionality' save the community management model of rural water supply? Water Resources and rural development; 9: 56-66. http://dx.doi.org/10.1016/j.wrr.2017.04.001
32. Liddle, ES., Fenner, R. 2017. Water point failure in sub-Saharan Africa: the value of a systems thinking approach Waterlines; 36: 2: 27pp. http://www.developmentbookshelf.com/doi/10.3362/1756-3488.16-00022
33. Howard, G., Calow, R., MacDonald, A., Bartram, J. 2016. Climate change and water and sanitation: likely impacts and emerging trends for action, Annual Review of Environmental Resources, 41: 253-276. https://doi.org/10.1146/annurev-environ-110615-085856
34. Cleaver., F, Whaley, L. 2018. Understanding process, power, and meaning in adaptive governance: a critical institutional reading. Ecology and Society; 23 (2): 49. https://doi.org/10.5751/ES-10212-230249.
35. Whaley, L. 2018. The Critical Institutional Analysis and Development (CIAD) Framework. International Journal of the Commons; 12 (2): 137-161. http://doi.org/10.18352/ijc.848
36. Whaley, L., MacAllister, D.J., Bonsor, H.C., Mwathunga, E., Banda, S., Katusiime, F., Tadesse, Y., Cleaver, F., MacDonald, A.M. 2019. Evidence, ideology and the policy of community management in Africa. Environmental Research Letters. https://iopscience.iop.org/article/10.1088/1748-9326/ab35be
37. Fallas, H. C., MacDonald, A.M., Casey, V., Kebede, S.,Owor, M., Mwathunga, E., Calow, R., Cleaver, F., Cook, P., Fenner, R.A., Dessie, N., Yehualaeshet, T., Wolde, G., Okullo, J., Katusiime, F., Alupo, G., Berochan, G., Chavula, G., Banda, S., Mleta, P., Jumbo, S., Gwengweya, G., Okot, P., Abraham, T., Kefale, Z., Ward, J., Lapworth, D., Wilson, P., Whaley, L. Ludi, E. 2018. UPGRO Hidden Crisis Research consortium: Project approach for defining and assessing rural water supply functionality and levels of performance. British Geological Survey (BGS) Open Report, OR/18/060, pp 25. http://nora.nerc.ac.uk/id/eprint/523090/
38. John Gowing, David Walker, Geoff Parkin, Alemseged Tamiru Haile, Demis Alamirew Ayenew (2020). Can shallow groundwater sustain small-scale irrigated agriculture in sub-Saharan Africa? Evidence from N-W Ethiopia. Groundwater for Sustainable Development Volume 10, April 2020, 100290.
39. Meta Meta / Addis Ababa University (2014) "Improving access to safe drinking water: Prospection for low-fluoride sources." Brief report presenting main findings – Addis Ababa", August 2014 , Meta Meta Research.
40. Jonathan Demenge and Lyla Mehta (2017). IDS Policy Briefing: Improving Livelihoods Through Better Road and Water Integration and Planning. Edited by Hannah Corbett and Vivienne Benson.

41. Steenbergen, F. van, K. Woldearegay, H.M. van Beusekom, D. Garcia Landarte, and M. Al-Abyadh (2014) "How to Make Water Wise Roads" IFAD, Rome

Credits

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