Improving water security in Ethiopia through integrated use of surface and groundwater resources

Story of change: Key findings & emerging impacts

Summary

- Addis Ababa's water supply is insufficient to meet current needs, leading to intermittent water supplies and inequalities in water access.
- REACH has developed a first of its kind dynamic water allocation model integrating both surface and groundwater resources for the upper Awash Basin where Addis Ababa city is located.
- Detailed characterization of the city's water supplies using environmental tracers offers implications for management to improve conjunctive use of surface and groundwater for sustainable supplies.
- Following regional dissemination and engagement with practitioners in other basins, the Lake Tana and Central Rift Valley basins are now updating their water allocation models to incorporate groundwater.

Photo: Behailu Birhanu, 2024

Addis Ababa

University of Oxford

REACH
Improving water security for the poor

Water & Land Resource Centre

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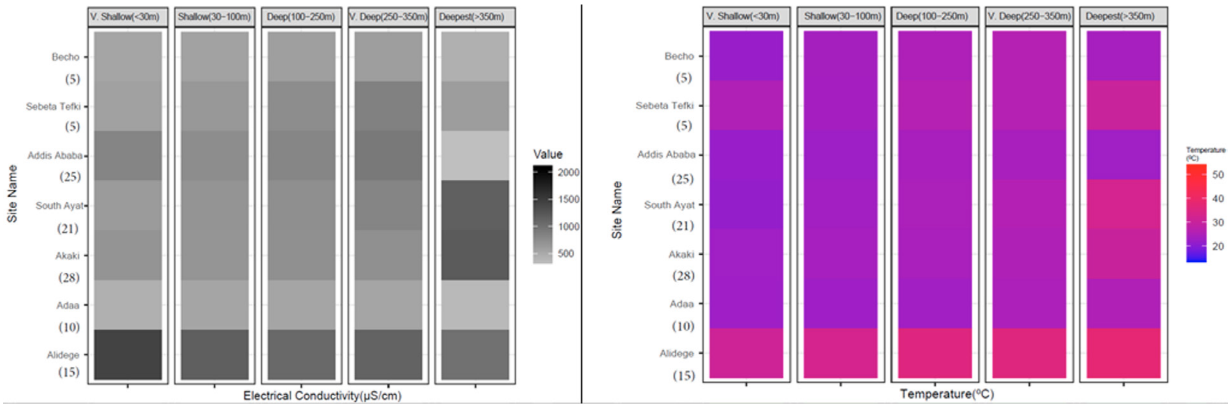
Figure 1: Heatmap of EC and Temperature profile at various locations in Addis Ababa (the numbers in the bracket indicate the number of boreholes from which the vertical EC and Temperature profile records were taken).



Introduction

As one of Africa's fastest growing cities, Addis Ababa's demand for water has sky-rocketed over recent decades due to population growth, increased per capita consumption, rural to urban migration, and growing water demand from industry. Water supplies across the city are already struggling to meet demand, with regularly interruptions to water services exacerbating inequities.

REACH has applied a range of methodologies to examine the implications of climate and population growth for Addis Ababa's water supply, providing evidence-based recommendations towards improving water security in the city. A crucial element of this work has been the development of a first-of-its-kind dynamic water allocation model integrating both surface and groundwater resources. Supported by this work, two other large basins, the Lake Tana and the Central Rift Valley Lakes basins, totalling 6 million people, have requested technical assistance and are updating their water allocation models to incorporate groundwater.

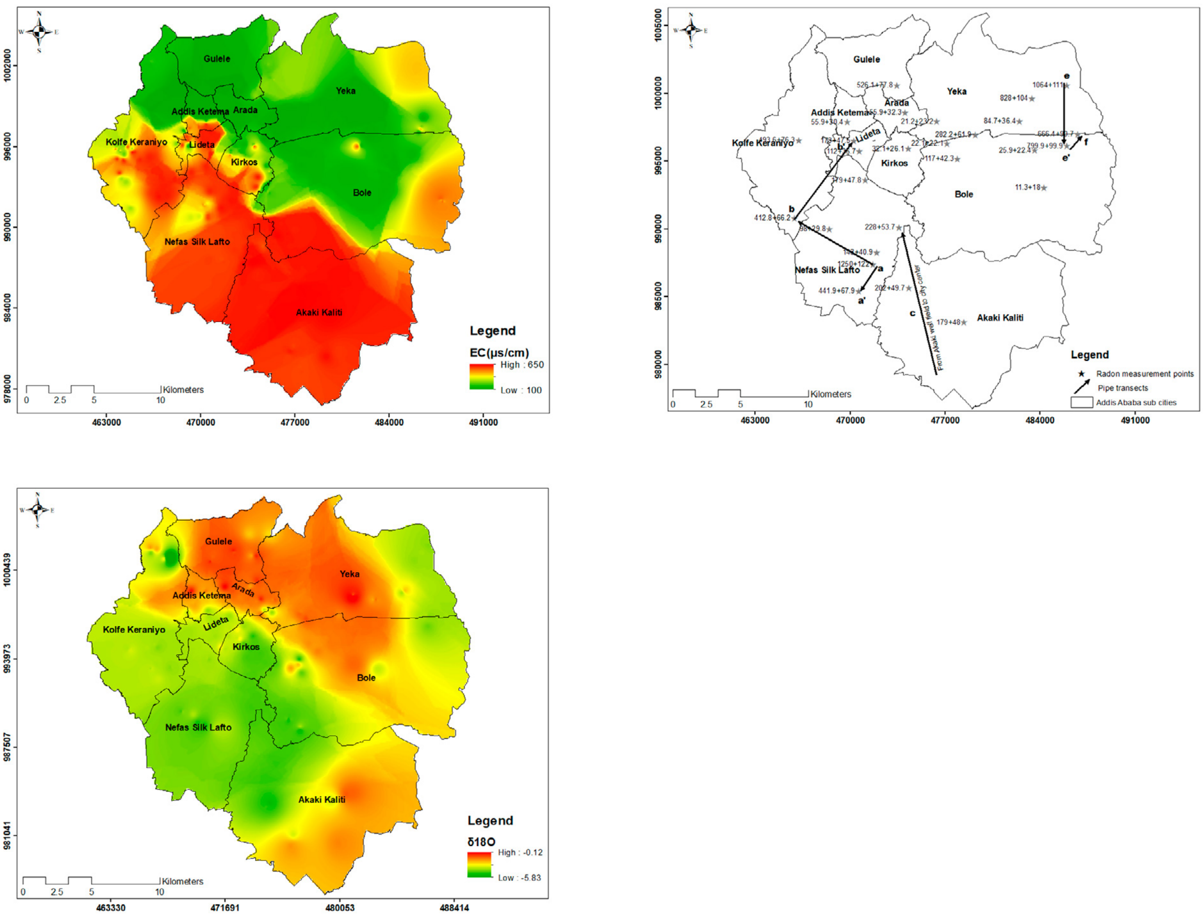
Scientific impacts

Dynamic water allocation model and methods for aquifer characterization

Whilst water allocation models commonly consider surface and groundwater supply sources separately, REACH researchers developed a dynamic water allocation model integrating both surface and groundwater supply sources. This first-of-its-kind dynamic water allocation model (using WEAP-MODFLOW) has been developed to model water demand-supply conditions in the upper Awash sub-basin where Addis Ababa city is located. The model has also been adapted to explore the city of Addis Ababa's water supplies, considering both water demand (population growth, water wasted through leakage) and supply (effects of climate change, effects of water supply expansion plans).

REACH research has also contributed to detailed characterization of Addis Ababa's water supplies through mapping of the relationships between surface and groundwater sources and examining patterns of groundwater flow beneath the city using environmental tracers (Water isotopes – $\delta^{18}O$–$\delta^{2}H$, Radon ^{222}Rn), Electrical Conductivity (EC) and temperature.

Figure 2: Spatial pattern of (A) EC, (B) d^{18}O (‰), and (C) ^{222}Rn (Bq/m^3) composition in selected Addis Ababa city tap waters. Low EC and high ^{18}O indicate the sub-cities where water is piped from surface water reservoirs. High EC and low ^{18}O indicate that pipes are connected to groundwater sources. Transition zones have mixed sources. (Source: Kebede et al., 2023)



Using vertical profiles of Electrical Conductivity and Temperature from measurements taken during boreholes drilling (Figure 1) is a new approach to understanding complex groundwater flow systems.

Application of ^{222}Radon to estimate water residence times in supply pipes

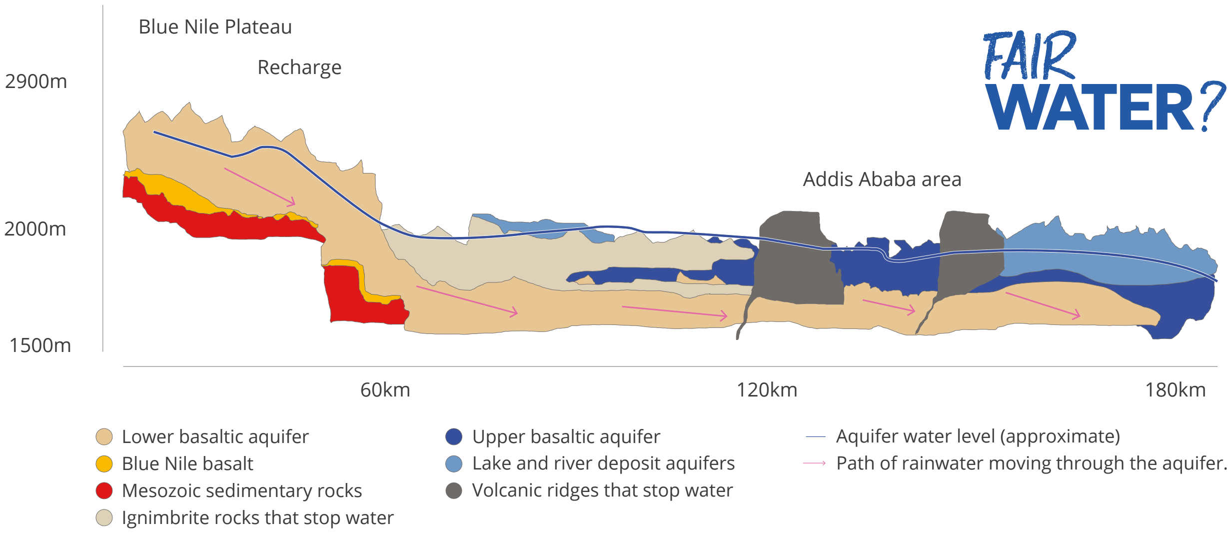
Addis Ababa city's old water supply distribution pipes are a major source of water loss due to leakage. Old pipes may pose water quality threats due to infiltration of exogenous substances into pipes under negative pressure. Indeed, the longer water stays in the pipe, the greater the probability of water contamination within the pipe network.

REACH research used measurements of electrical conductivity to characterize water quality in selected tap water systems, and used a ^{222}Rn radioactive isotope, a tracer not previously used in this way, to determine pipe water residence time.

Integrating applications of isotope and citizen science to identify priority areas

Figure 2 shows how environmental tracers have been used to map how different areas of Addis Ababa get water from groundwater (shallow and deep boreholes), surface water, or a mixture of both ground and surface water. A citizen science approach was used to explore household experiences of water supply interruption across the city.

Figure 3: Illustrative cross-section from the REACH-inspired Fair Water? museum exhibition showing how deep groundwater systems in the Addis Ababa region is recharged by rainfall on the Blue Nile Plateau. Shallow groundwater systems are recharged from local rains. (Image credit: Oxford University Museum of Natural History).



Volunteers from 30 households in six selected sub-cities engaged in this research, recording interruptions to their water supplies over two ten-day snapshot periods in the wet and dry season in 2020 (Figure 4). This survey complements the isotopic and electrical conductivity records of Addis Ababa city tap water and identifies sub-cities that need immediate water supply intervention. Also, by mapping which households are connected to surface water reservoirs, and which to shallow and deep groundwater systems, it provides additional information on climate change vulnerability in different parts of the city.

Key findings

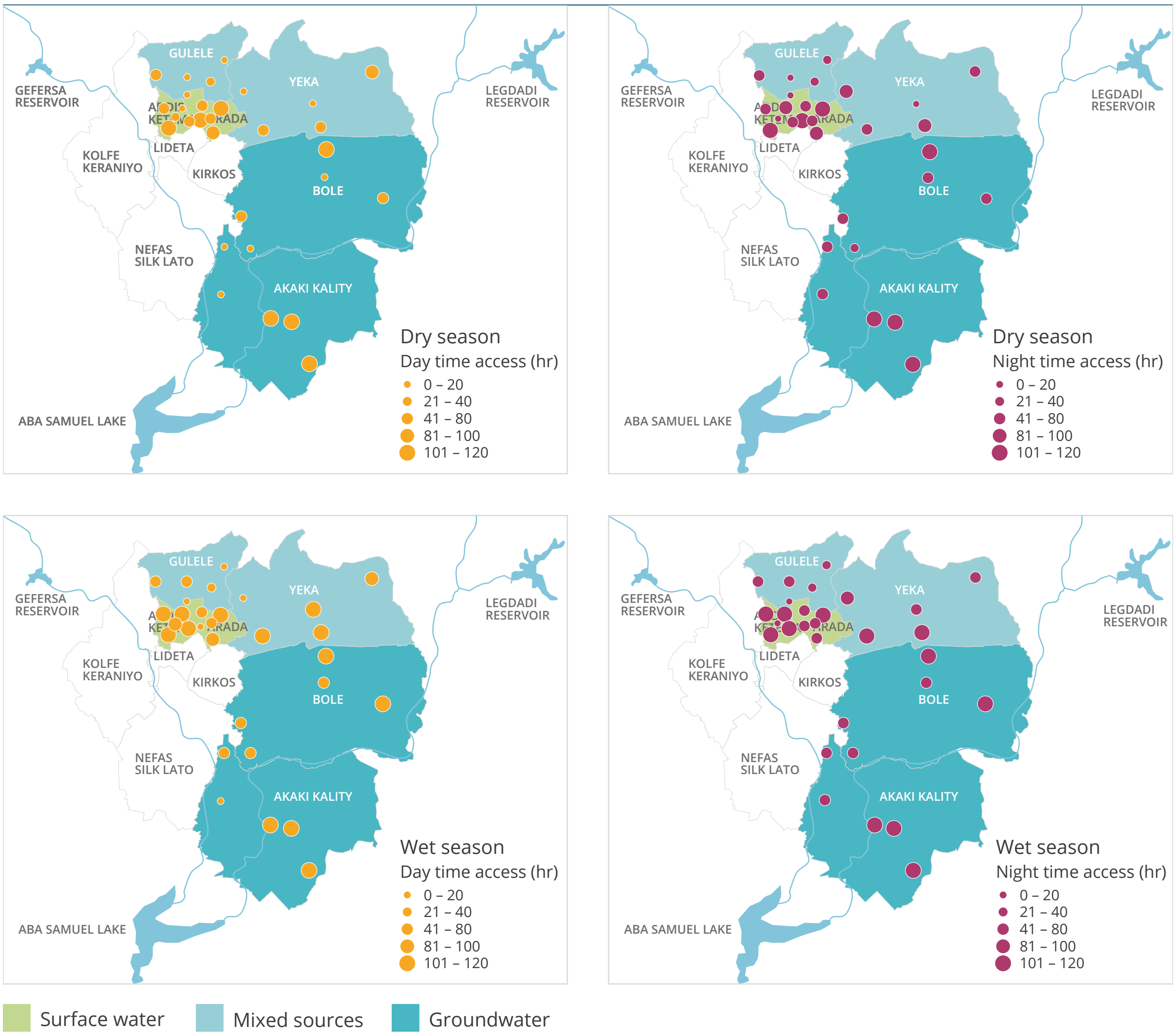
Groundwater flow characterization and implications for management

Understanding groundwater recharge, flow and discharge is important for sustainable water resource management decisions. The groundwater systems supplying Addis Ababa city are comprised of:

- Deep groundwater systems which are connected to regional groundwater flow originating from the Ethiopian highlands (Figure 3), and,
- Shallow groundwater systems which are becoming recharged from local rains.

The local recharge zones are located in highly urbanizing and industrializing areas, with consequent risks of recharge reduction and pollution. Attention should be given to protecting groundwater resources from contamination. Managed Aquifer Recharge suitable sites should be mapped to guide decision-making on where MAR intervention could be applied effectively.

Figure 4: A snapshot survey of dry (May 2020) and wet (August 2020) seasons of water interruption in six selected Addis Ababa sub-cities; (a) dry season daytime access to water, (b) dry season night time access to water, (c) wet season daytime access to water, (d) wet season night time access to water. (Source: Birhanu et al., 2023).



Need for well-managed conjunctive use of surface and groundwater

The integrated water allocation model developed through WEAP-MODFLOW dynamic linkage shows that Addis Ababa's water supply is insufficient to meet current demand. If current groundwater abstraction rates continue, groundwater resources are at risk of depletion. Additional surface water reservoirs are planned outside the city at Gerbi and Sibilu, although currently delayed due to economic and other constraints. Our modelling suggests that even these expansion plans will not fully meet growing demand due to population growth, expanding industries and water leakage.

Under climate projections, drier conditions may also stress city water supply sources in future. Groundwater sources are potentially more climate-resilient during drought periods. Action is needed to better monitor and manage groundwater use, and to improve the conjunctive use of surface and groundwater to support sustainability for Addis Ababa's water supplies. Water supply expansions should be integrated with other non-engineering interventions (e.g. demand management), which can minimize water loss and enhance water use efficiency.

Links between energy supply, water reliability and water quality in urban areas

The citizen science household water interruption study suggests that households connected to groundwater supply sources are more vulnerable to water interruption than those connected to surface water sources. This is mainly attributed to the frequent power outages in the city, affecting borehole pumps. REACH research shows borehole flow interruption is accompanied by changes in water quality of piped waters by demonstrating the presences of exogenous substances in pipe network following negative pressure development.

Emerging water quality concerns

Research by REACH on emerging contaminants (natural and synthetic organic compounds) shows that shallow groundwater and rivers are affected by pesticides, artificial sweeteners, pharmaceuticals, veterinary drugs, and surfactants. Some emerging contaminants are observed in tap water originating from both surface and shallow groundwater supply sources (pesticides, personal care products, stimulant drugs, surfactants, pharmaceuticals).

Policy and practice impact

As is the case across Ethiopia, groundwater is commonly left out of allocation models. REACH's work and engagement with practitioners is providing increasing evidence about how water allocation models can and should integrate groundwater. However the research also highlighted that a move to decentralized water sourcing tapping into groundwater will have water quality challenges, as most of the shallow boreholes have been shown to contain contaminants (including emerging contaminants which were identified in some piped tap waters connected to shallow boreholes).

The results from REACH work were presented at locally organized workshops with experts from Awash, Abay, and Rift Valley Lake Basin offices.

Following these engagements, the Abay Basin Office and Rift Valley Lakes Basin Office have requested further technical support to update their models, respectively for the Lake Tana sub-basin (two million people) and the Central Rift Valley Lakes (four million people). The Rift Valley Lake Basin has already invested funding and commissioned a technical consultant to improve the model.

REACH-Ethiopia water allocation modelling outputs have been presented at international platforms and received the best presentation award at the International Conference on Water Resources Management and Sustainability: Solutions for Arid Regions, DUBAI-2022.

Capacity building

Capacity building has been a major element of this work. REACH has:

- Conducted training workshops on water allocation modeling for experts working at AAWSA, MoWE, and Basin Offices (Awash, Abay Rift Valley). The participants are mostly early to mid-career professionals working in the water sector.
- Co-organized the Addis Ababa Adaptation Network Workshop with AAWSA and IWMI and discussed the policy brief we prepared with experts from AAWSA.
- Involved Masters and Ph.D. students from Addis Ababa, Addis Ababa Science and Technology, and Bahir Dar Universities in Ethiopia in work on dynamic water allocation modelling.

Research outputs

Birhanu, B., Kebede, S., Charles, K., Taye, M., Atlaw, A. and Birhane, M. 2021. Impact of natural and anthropogenic stresses on surface and groundwater supply sources of the upper Awash sub-basin, central Ethiopia. *Frontiers in Earth Science*, 9: 656726. doi: 10.3389/feart.2021.656726

Hailu, K., Kebede, S., Birhanu, B., Lapworth, D. 2024. Tracing contaminants of emerging concern in the Awash River basin, Ethiopia. *Journal of Hydrology, Regional Studies*, 54: 101869. doi: 10.1016/j.ejrh.2024.101869

Hailu, K., Birhanu, B., Azagegn, T., Kebede, S. 2023. Regional groundwater flow system characterization of volcanic aquifers in upper Awash using multiple approaches, central Ethiopia. I*sotopes in Environmental and Health Studies Journal*, (accepted).

Kebede, S., Hailu, K., Siraj, A. and Birhanu, B. 2023. Environmental isotopes ($\delta^{18}O$–$\delta^{2}H$, ^{222}Rn) and electrical conductivity in backtracking sources of urban pipe water, monitoring the stability of water quality and estimating pipe water residence time. *Frontiers in Water*, 5: 27. doi: 10.3389/frwa.2023.1066055

Kebede, S., Charles, K., Godfrey, S., MacDonald, A. and Taylor, R.G. 2021. Regional-scale interactions between groundwater and surface water under changing aridity: evidence from the River Awash Basin, Ethiopia. *Hydrological Sciences Journal*, 66 (3): 450–463. doi: 10.1080/02626667.2021.1874613

Other outputs

Tracing Emerging Contaminants in the Awash River Basin, Ethiopia. REACH Blog, September 2024

Addis Ababa city water supply challenges: is doing nothing an option? REACH Blog, May 2023

Groundwater for climate resilience in the Horn of Africa. REACH Blog, February 2023

Addis Ababa's water demand-supply conditions: hydrological challenges and policy options. REACH Policy brief, January 2023.

The future of sustainable water resources management. REACH Blog, May 2022.

Improving urban water supply security through the integrated use of surface-groundwater resources. REACH Blog, May 2021.

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Story of change themes

- Groundwater
- Land
- Coasts
- Gender
- Schools
- Services
- Health
- Climate
- Cities
- Basins

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