REACH Improving water security for the poor

Mid-programme synthesis

Report on findings from the Awash River basin

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Foreign, Commonwealth & Development Office

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Who we are

REACH is a global research programme funded by the Foreign, Commonwealth & Development Office (FCDO) to improve water security for the poor by delivering world-class science that improves policy and practice. REACH is led by the University of Oxford in partnership with a global network of collaborators:

- UNICEF
- Bangladesh University of Engineering and Technology
- University of Nairobi
- Water and Land Resource Centre, Addis Ababa University
- International Centre for Diarrhoeal Disease Research, Bangladesh
- International Food Policy Research Institute
- International Water Association
- IRC International Water and Sanitation Centre
- Skat Foundation hosting the Rural Water Supply Network
- University of Dhaka

EXECUTIVE SUMMARY

REACH is a long-term research programme, funded by UK Aid from the FCDO, that is working to improve water security for 10 million people across Africa and Asia. We work through science-practitioner partnerships in close collaboration with governments towards transformative change in the water sector for the reduction of poverty and inequalities.

REACH has been working in the Awash River basin in Ethiopia since 2015 to improve water security with long-term stakeholder engagement. We have been working closely with the Awash Basin Development Office (AwBDO) as well as other departments of the Ministry of Water, Irrigation and Electricity (MoWIE), and UNICEF. This report provides an update on work to date, and introduces our programme of research from 2020-2024.

Some of the key achievements detailed in this report include:

In collaboration with AwBDO, REACH researchers have addressed gaps in the Awash basin's Water Evaluation and Planning (WEAP) tool. This has improved the usability of the tool for operational water allocation. This is a critical contribution to moving towards greater water security in the basin.

Future climate projections show an increase in water deficiency in all seasons and for parts of the basin, due to a projected increase in temperature and decrease in precipitation. This decrease in water availability will increase water stress in the basin, further threatening water security for different sectors.

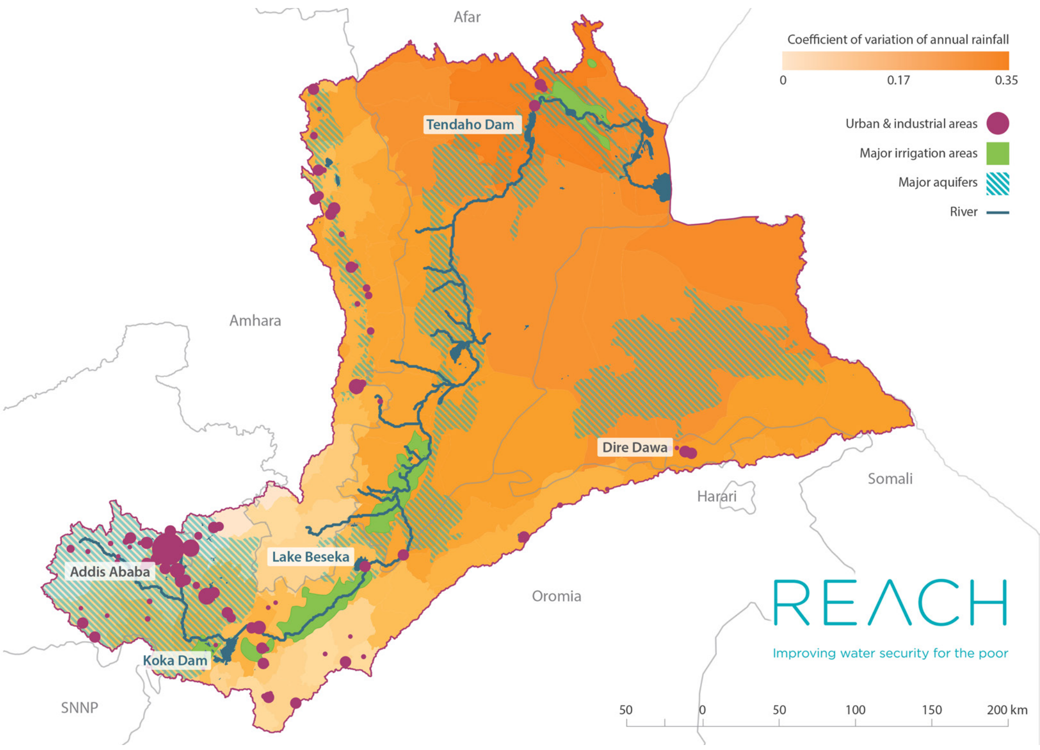

Figure 1. The Awash River Basin (source: REACH)

There are opportunities for mainstreaming equity in river basin management. REACH researchers have identified key bottlenecks preventing the realisation of equitable water security in the Awash. This offers a foundational basis for developing more equitable institutional and governance arrangements for water security.

There is an important relationship between land degradation and water security. Researchers in the REACH programme have been working to understand and model sediment loads in the Awash River with a view to understanding potential policy interventions.

In the Upper Awash basin, uncontrolled abstraction from the Upper Awash aquifer will likely affect river flow. REACH is engaged in novel groundwater science to improve understanding of groundwater and groundwater-surface water interactions in the basin.

The water quality of the river varies across the year from season to season. Using the INCA water quality dynamic modelling software tool, REACH researchers have contributed to a more comprehensive understanding of flows of pollutants and how they vary in the Awash.

Collaborative water allocation, where all water users are included in water allocation decisions, can improve water access and equity in the basin. Water allocation is critical for sustainable management of water resources in a basin with rapidly growing competition. Without effective management, climate variability will reduce productivity and threaten food security.

Studies in hydro-economics reveal that competing water security outcomes in the Awash River Basin require management of distributional risks and benefits. REACH researchers have explored the multi-sectoral and distributional economic impacts of rainfall shocks and the economic implications of irrigation for smallholder farmers across the basin.

Credit: Alice Chautard/REACH

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INTRODUCTION

The REACH programme aims to generate improvements in water security for the poor by working at the interface of water security, risk and poverty research and practice. We recognise that water security has multiple priorities that can compete for scarce resources. As such, our work simultaneously considers water security outcomes of resource sustainability, inclusive services and sustainable growth, and the trade-offs between them. We take an interdisciplinary, risk-based research approach which is vital for tackling the many challenges facing water resources and the water sector.

The Awash River basin has been studied for decades; one of the earlier surveys of the Awash was conducted by the UN Food and Agricultural Organisation (FAO) in 1965 to, "appraise the resources of the basin in land and water, and their potential development." Much has changed since then: the basin is now critical for the national economy and supports the livelihoods of 21 million people. Agriculture, industries and urban areas have expanded to the extent that demand on surface water now outweighs the available resources. Deteriorating water quality, alongside the impacts of climate change, are likely to intensify the existing challenges in the basin.

Throughout the REACH programme we have been steered by, and worked with, AwBDO, MoWIE as well as regional water bureaus, and UNICEF. We have designed our research to inform the decisions that are being made in the Awash basin, including work to improve water allocation decision-making tools, increase climate information, understand landscape changes, improve groundwater science, instigate water quality modelling and unpack the institutional and social arrangements that govern water security.

The purpose of this mid-programme report is to provide an overview of REACH's research in the Awash River basin since the beginning of the programme in 2015. The findings in this report span the physical and social sciences, contributing to the knowledge base and illuminating on sustainable growth pathways. We draw out the key policy implications in different areas of the work so far.

REACH's research is ongoing until 2024 and future work will build on our findings so far and continue to address key challenges in four thematic areas: 1) climate resilience, 2) water governance and institutions, 3) inequalities in water security and 4) water quality. By working across science-practitioner partnerships, in collaboration with local stakeholders, our REACH findings will continue to contribute policy-relevant scientific knowledge to address these areas and bring about transformational change.

RESEARCH ACTIVITIES 2015-2020

1. Improved water allocation tools

Appropriate and context-specific allocation tools can go some way to planning for future changes in the basin, ensuring equitable outcomes and linking surface water and groundwater management. The Awash Basin Development Office (AwBDO) developed a WEAP (Water Evaluation and Planning) tool for hydrological modelling and water allocation between demand sectors across all woredas in the basin. The AwBDO WEAP model has a detailed estimate of woreda-level water demand and uses in-situ hydroclimate data.

In collaboration with the AwBDO, REACH researchers have expanded the model design to fill operational gaps. The model was improved with:

- Recreation of sub-catchment boundaries using finer resolution digital elevation model
- Better representation of land use/cover in the model
- Calibration of model parameters
- Simplification of demand nodes
- Inclusion of groundwater sources and realistic future climate scenarios
- Addition of agricultural water demand below Koka dam.

These changes improve functionality of the tool, support better management of water resources in the basin, and help to identify where water access is restricted for downstream users.

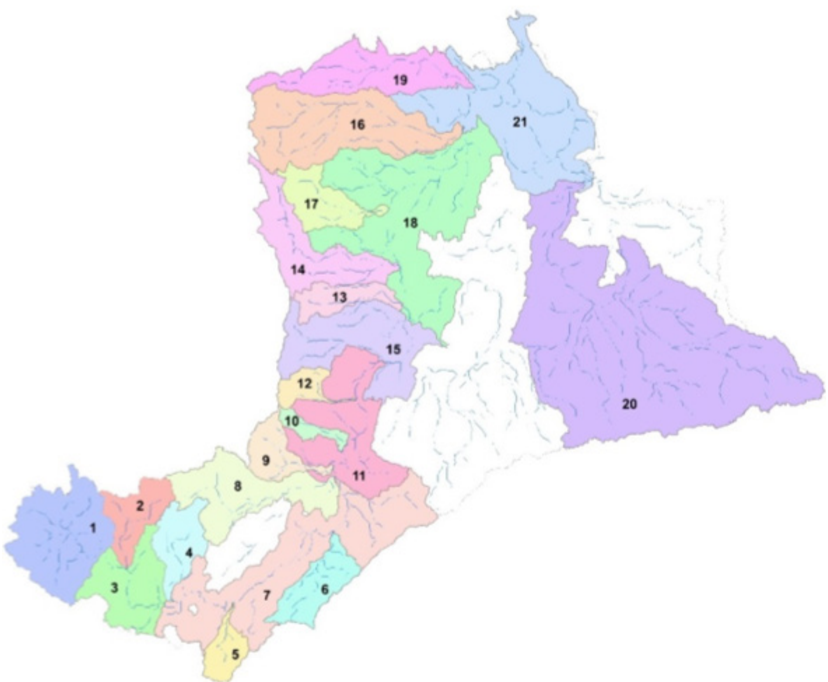


Figure 2. Basin and sub-basin delineation of the Awash River basin. The white areas do not contribute surface flow to the river

Improvements to the WEAP model

We delineated the Awash basin and the sub-catchments using the 30m HydroSHED DEM data which is freely available from https://hydrosheds.cr.usgs.gov/dataavail.php. The delineation reveals that portions of the basin do not contribute surface flow to the main river (white areas in Figure 2).

To simplify the presentation of the model and to make the model run faster, we aggregated the demand nodes from woredas to sub-catchments; each sub-catchment now has one demand node. The demand node represents the aggregated demand for all woredas located in the sub-catchment. The new simplified schematic diagram is shown in Figure 3. Water loss for domestic demand due to leakage and waste of distributed networks is set at 20% of the domestic water demand. This is based on the expected efficiency of water supply networks for year 2020. The changes to WEAP have been more fully reported by Hirpa (2019).

Integration of MODFLOW

MODFLOW is a three-dimensional finite difference groundwater flow model. While groundwater can be included in WEAP, it does not allow feedback that can help understand the pressure abstractions place on groundwater. REACH has linked MODFLOW with WEAP to provide a novel configuration that integrates surface water-groundwater (SW-GW) resources. This MODFLOW-WEAP integrated tool is designed to support analysis of both surface water and groundwater allocation problems involving complicated hydrological, environmental and socioeconomic constraints and conflicting management objectives. Most importantly, the integrated model can be used as an active tool to support water management decisions incorporating the continuously changing natural and anthropogenic stresses.

The WEAP-MODFLOW integration can be used as a water management decision support tool. The tool is being used

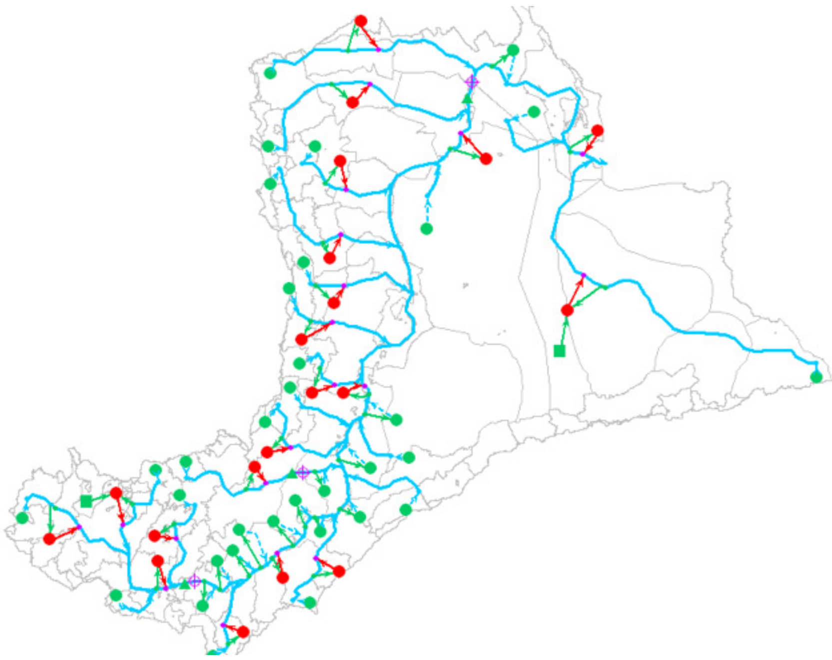


Figure 3. The schematics of the new WEAP setup.

to evaluate the impact of scenarios of natural and anthropogenic change and/or demand and supply side stresses on both surface water and groundwater resources. By developing demand and supply side scenarios, water management aspects which require immediate interventions can be suggested. The outcomes of these scenarios are discussed at more length in the following section.

Research output

Hirpa, F. A. 2019. Water allocation in the Awash River basin: Advancing the Awash Basin Authority WEAP model, *REACH Research Report*.

2. Novel groundwater science

Hydrogeologists in the REACH team have been working towards a better understanding of groundwater resources, flows, recharge and surface water linkages in the Awash River basin. There is now more information about the groundwater potential, the natural and anthropogenic stresses and the likely climate change impacts on groundwater in the Upper Awash basin.

Upper Awash basin groundwater potential

Groundwater in the Upper Awash basin moves from North-North West to South-Southwest in the basin. There is about 330 Mm^3 net annual groundwater contribution to the Upper Awash river, making the Upper Awash a gaining river. This illuminates the importance of the groundwater system in maintaining the flow of the Awash River and reservoirs storage. There is net contribution of the groundwater to the river while the river contributes nearly 23 Mm^3 of water to the groundwater. This is based on convergence evidence from base flow separation, HYDRUS 1D and groundwater flow modelling recharge estimation techniques.

Most of the existing groundwater abstraction points are located in Akaki catchment, where Addis Ababa city and most industries are located, which makes Akaki catchment the most stressed aquifer in the basin. In Akaki catchment, more than a 10-metre groundwater level decline is predicted in 2030. The impact in the groundwater storage is not only because of groundwater abstraction for domestic water supply, but the sum effect of noticeably increasing abstraction for industrial uses.

Natural and anthropogenic stresses on SW and GW resources in the Upper Awash basin

Population projection scenarios indicate that an additional 210Mm^3 water will be required for the Akaki catchment in 2030, mostly for Addis Ababa. For Melka Kunture (Holeta, Teji, Asgori, Tulubolo, Ginchi towns), Mojo (Mojo, Bishoftu and Dukem towns) and Koka catchments (Koka town) domestic consumptions, 16Mm^3, 11Mm^3 and 6Mm^3 of additional water will be required in 2030 from 2015, respectively.

There are large volumes of unaccounted for water in major towns in the Upper Awash. The minimum average water loss due to leakage is 13% with only three functional boreholes (in Koka). The maximum average

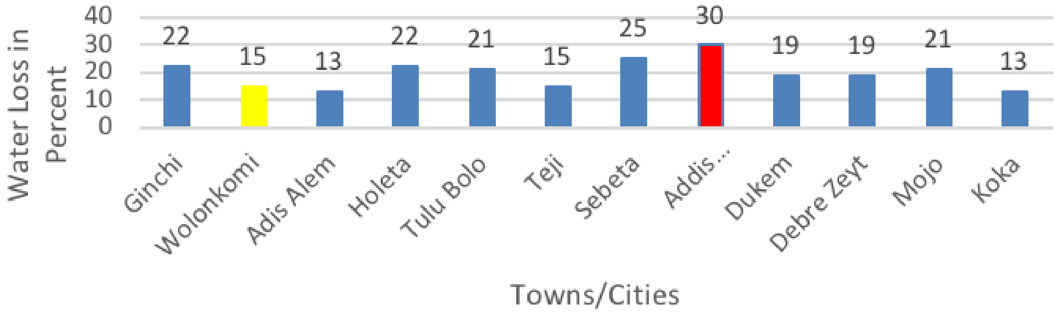


Figure 4. Unaccounted for abstracted groundwater resources in the major urban settlements in Upper Awash Basin

loss estimate is about 30% in Addis Ababa with more than 160 functional boreholes (Figure 4). The domestic water demand in the Upper Awash basin is all from groundwater resources. Therefore, significant urban water losses due to leakage from poorly maintained infrastructure is exacerbating challenges related to water allocation. Efforts should be made to minimise these water losses.

Most of the towns/cities in the UA basin pump only for 4-8Hrs in a day due to unavailability of energy/electric power. Hence, BHs are serving below their designed potential as a result of continuous power interruption (Table 1). Which underlines role of energy availability to enhance groundwater use for domestic water demand, especially for rural community.

Impact of climate change on groundwater in the Upper Awash River basin

The climate conditions for the baseline period (2005 to 2019) and for the scenario period (2020 to 2030) have been applied on the WEAP-MODFLOW link to assess the impact of temperature and precipitation change scenarios on future groundwater availability. Groundwater discharge flux to the river will be relatively higher compared to the baseline climate scenarios in dry months. Streamflow simulation under different climate scenarios resulted in a variable response of different land use-land cover for similar climate change scenarios. Groundwater discharge to the river is more sensitive to climate change in urban settings than in agricultural areas.

Table 1. Comparison of actual abstraction and design capacity of boreholes for selected towns in Upper Awash Basin

Town	Design capacity (m^3/day)	Actual abstraction (m^3/day)	Percentage difference	Number of functional wells
Debrezeit	39969	13179	67	21
Holota	5141	1521	70	9
Ginchi	1224	572	53	4
Addis Alem	1296	900	31	3
Wolnkomi	605	343	43	1
Sebeta	28426	9101	68	21
Teji	2566	1341	48	4

KEY FINDINGS

- Around 1.12 billion m^3 of water recharges the Upper Awash aquifer system annually. Nearly 360 million m^3 of water gets abstracted each year, mainly for domestic and industrial uses.
- Uncontrolled abstraction from the Upper Awash aquifer will likely affect the flow in the rivers.
- In Melka Kunture, Mojo and Koka catchments, water demand can be satisfied by additional groundwater supply schemes without significantly affecting the groundwater resource.
- Population projection scenarios indicate greatly increasing groundwater demands in the Upper Awash – doubling for Addis Ababa from 2015 to 2030.
- By minimizing water loss by half of the average reported, up to 6M m^3 of unmet water demand can be recovered per month in the Addis Ababa water supply system.

POLICY NOTE

A focus on tackling water loss in infrastructure systems will have benefits for groundwater management and efficient use.

Research Output

Kebede, S. and Zewdu, S. 2019. Use of 222Rn and δ18O-δ2H Isotopes in detecting the origin of water and in quantifying groundwater inflow rates in an alarmingly growing lake, Ethiopia. *Water MDPI*, 11, 2591.

3. Future climate trends

To improve water security in an era of climate change, it is necessary to understand future climate trends and their impact on the availability of water resources. REACH researchers have been working to understand future trends in climate in the Awash basin to support decision-making. They have quantified the potential impact of climate change on water availability in the Awash basin in different seasons[1] and explored how temperature will change in the coming century.

1 The future water availability was estimated as the difference between precipitation and potential evapotranspiration projections using the representative concentration pathway (RCP8.5) emission scenarios after the climate change signals from the climate models are transferred to the observed data.

Model evaluation for smarter climate information

We used a model evaluation approach to determine which future projections to use, and how to understand them as seen in Figure 5. We have been trying to understand the physical processes which influence the biases in the period between the two main rainy seasons, and are examining how moisture flux into the region varies to compare how models represent the climate and moisture sources. This work will also allow us to provide a better physical context for future changes, especially in this marginal climate zone.

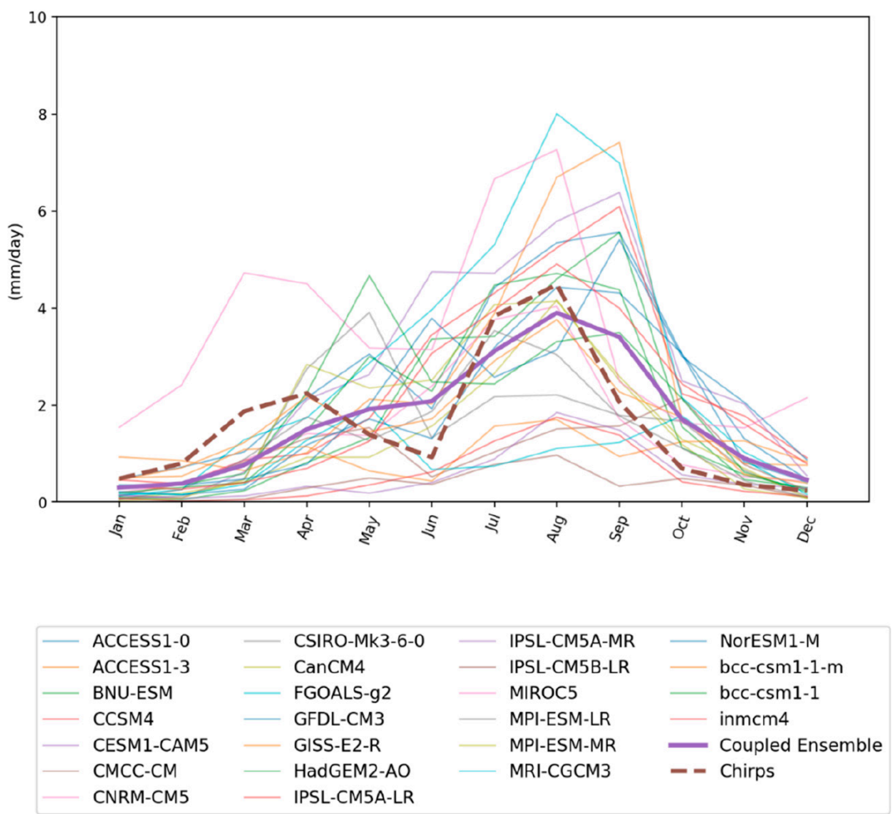


Figure 5. Annual cycles of monthly averaged rain rates (mm/day) in the Awash basin from atmosphere-only AMIP models. Observational climatologies are shown in dashed lines, while individual model climatologies are shown as thin translucent lines and the ensemble average is shown as a thick solid line. All rainfall was masked for the Awash basin and for the period 1981-2005.

KEY FINDINGS

- Across the basin, there are increasing trends in temperature in the June and March-May periods. This increasing trend in temperatures is occurring during what is the hottest and driest period for the middle and lower basin woredas.

- Three models (MPI-ESM-MR, HadGEM-AO, GFDL-CM3) were found to perform well in the Awash and NW Ethiopia in revealing basin-wide climate averages but miss features that can reveal the local climate because they are too coarse. We are working to understand the physical reasons why models can't reproduce the local climate, and this information will be useful for assessing model skill in future model ensembles.

The impact of climate change on future water availability

Three climate models, selected from the above evaluation, from Coupled Models Inter-comparison Project phase 5 (CMIP5) were used to explore future changes in precipitation in three future periods (2006–2030, 2031–2055, and 2056–2080). The models were selected based on their performance in capturing historical precipitation characteristics. The baseline period used for comparison is 1981–2005.

This study presents the most probable projections for the impact of climate change on precipitation in the Awash, using a methodological approach based on selecting best performing GCMs followed by a change factor method that accounted for sampling uncertainty due to the choice of periods.

Results for the mid-future period (2031-2055) (Figures 6-8)

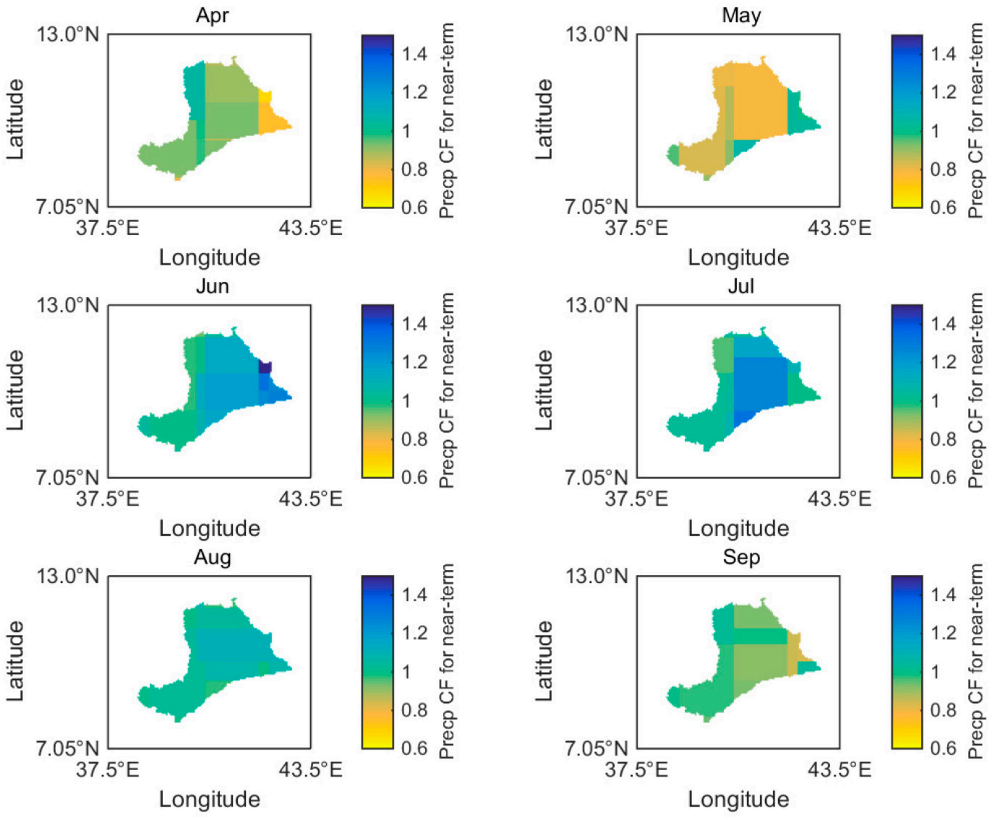


Figure 6. Precipitation change factors for April to September months for the near-term period, 2006–2030

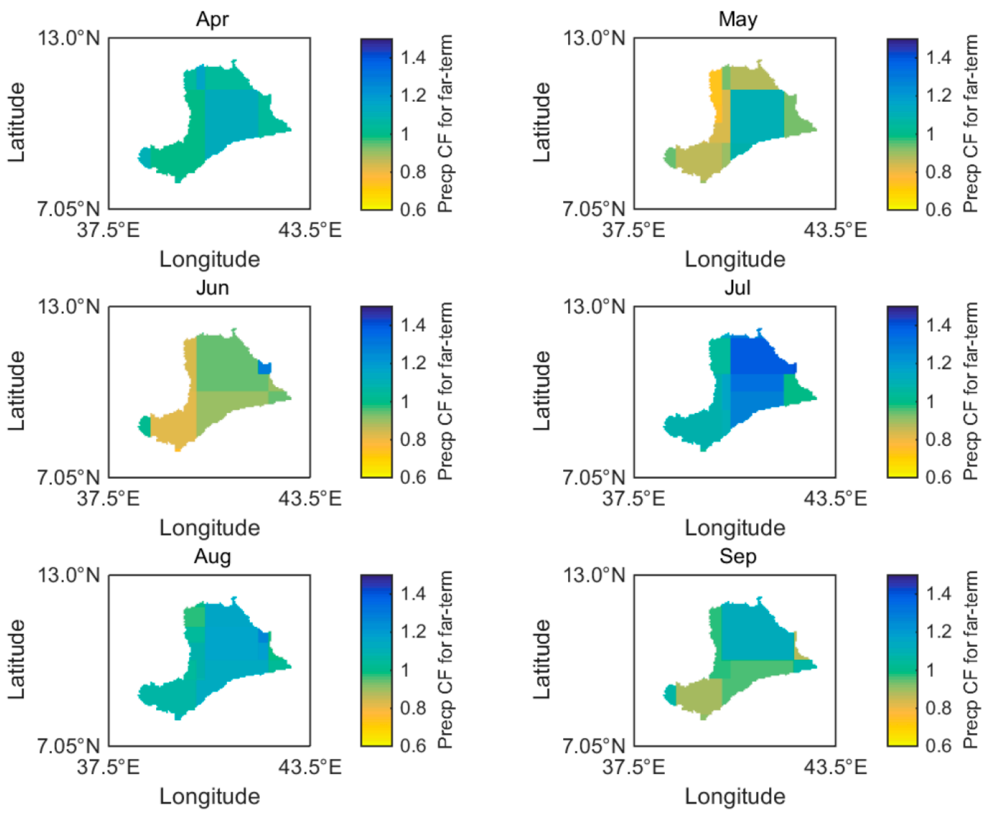


Figure 7. Precipitation change factors for April to September months for the far-term period, 2056–2080

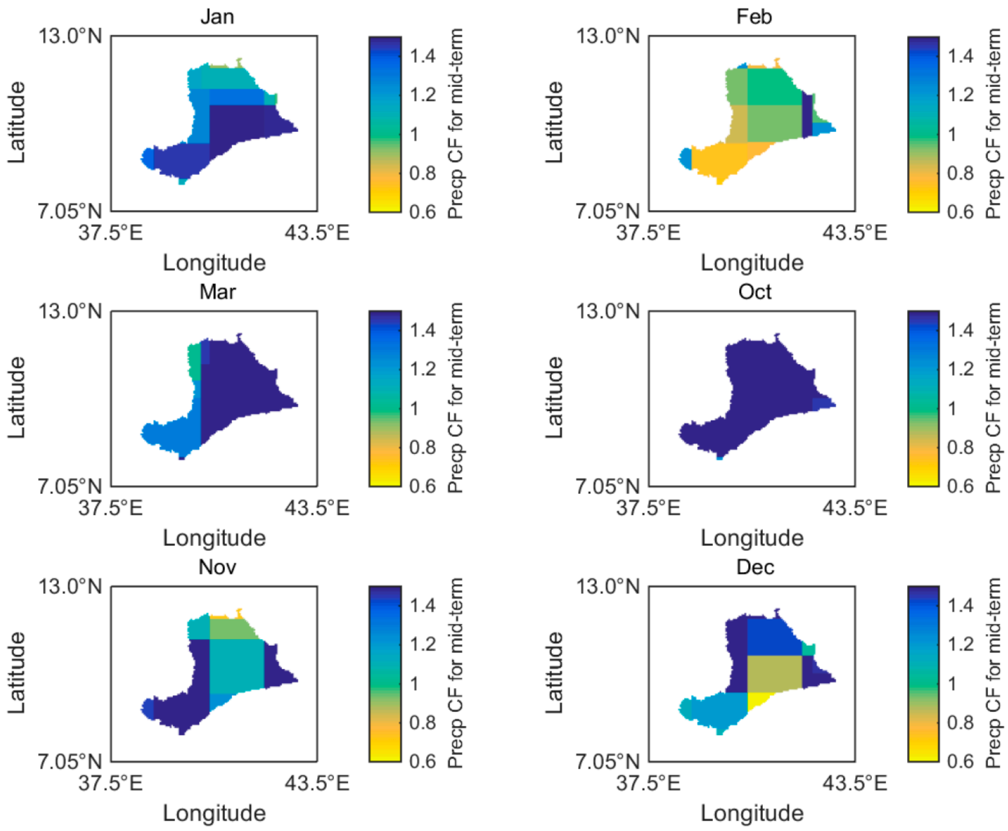


Figure 8. Precipitation change factors for January to March and October to December months for mid-term period, 2031–2055

Precipitation change factor

- The change in precipitation in the MAM (March-April-May) season has wider range
- March precipitation is projected to increase significantly in the entire basin by more than 50%
- April precipitation increases in the eastern basin by 10% to 40% while the western parts remains the same
- May precipitation show decrease in western part and increase in the eastern basin
- July precipitation shows slight increase in the order of 10%
- The lowlands get higher increases in precipitation in Aug and Sep

Future temperature projections

We have explored future temperature in the basin since future projections of temperature are much more robust than projections of changes in rainfall patterns. Figure 9. shows 25-year June temperature distributions from the full CMIP5 model ensemble from the atmosphere-only AMIP, fully coupled Historical, and future RCP4.5, and RCP8.5 simulations.

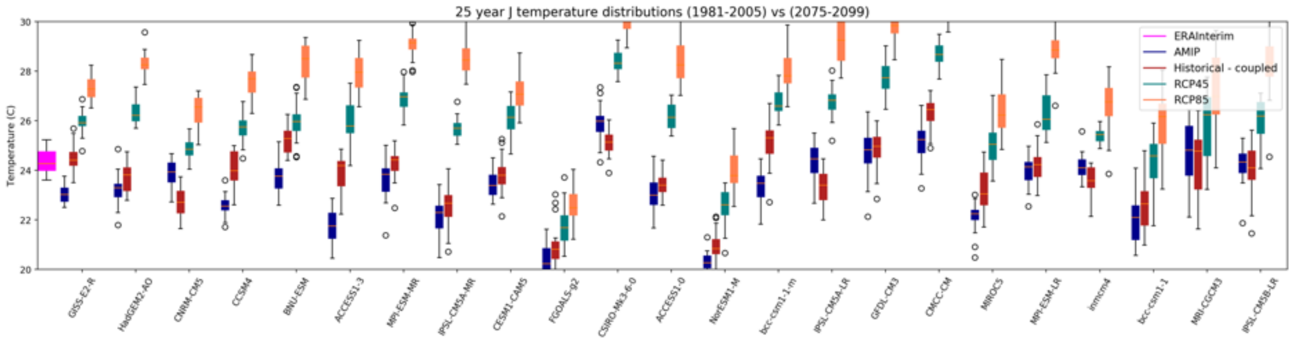


Figure 9. June temperature distributions from models in their Historical coupled, atmosphere-only (AMIP) runs, and future climate scenarios RCP4.5 and RCP8.5 in the Awash basin. Historical scenarios are for the 1981-2005 period and future scenarios are for the 2075-2099 period. The ERA-Interim reanalysis June temperature distribution is shown for comparison.

KEY FINDINGS

- Generally, the climate projections showed that the current challenge of the Awash basin in terms of water stress is something that will be intensified under a warming climate.
- The projections for the future three periods show an increase in water deficiency in all seasons and for parts of the basin, due to a projected increase in temperature and decrease in precipitation. This decrease in water availability will increase water stress in the basin, further threatening water security for different sectors, which are currently increasing their investments in the basin such as irrigation.
- Climate models agree on future warming in the basin for most models there is over a 4 degree change by the end of the century.
- From the precipitation projections, June will be drier during the far-term period while the near and mid-term projected a slight increase in precipitation. However, since temperature is increasing throughout the future projections, water availability will remain a challenge this month.

POLICY NOTE

It is critical that climate resilience is mainstreamed in water planning for the Awash River basin, recognising a hotter future with less available water and how this will increase competition for water resources.

Research Outputs

Dyer, E, Washington, R and Teferi Taye, M. 2019. Evaluating the CMIP5 ensemble in Ethiopia: Creating a reduced ensemble for rainfall and temperature in Northwest Ethiopia and the Awash basin. *International Journal Climatology*, 1– 22.

Hirpa, F. A., Alfieri, L., Lees, T., Peng, J., Dyer, E., & Dadson, S. J. 2019. Streamflow response to climate change in the Greater Horn of Africa. *Climatic Change*, 156(3), 341–363.

Taye, M. T., Dyer, E., Charles, K. J. & Hirons, L. C. 2020. Potential predictability of the Ethiopian summer rains: understanding local variations and their implications for water management decisions. *Science of The Total Environment*, 142604.

Taye, M. T., Dyer, E., Hirpa, F. A., & Charles, K. 2018. Climate change impact on water resources in the Awash basin, Ethiopia. *Water (Switzerland),* 10(11), 1–16.

How can we increase capacity for water-related climate adaptation? Lessons and opportunities from Ethiopian river basins. Dr Ellen Dyer, REACH Blog, October 2019.

What we know, don't know and need to know about future East African Climate | 4 September cross-project meeting. Dr Ellen Dyer, Dr Laura Burgin and Dr Linda Hirons, October 2019.

Ethiopia's future is tied to water – a vital yet threatened resource in a changing climate. Dr Meron Teferi Taye and Dr Ellen Dyer, August 2019.

4. Reducing inequities in water security

There are opportunities for mainstreaming equity in river basin management in Ethiopia but this will require political commitment and addressing institutional challenges. There are stark inequities in water security in the Awash River basin that exist between water user groups (agriculture, industry, urban, rural), upstream-downstream inequities as well as within woredas and communities.

Intermittent and unsafe government water supplies

In general, formal government water supplies were found to be intermittent and of poor quality. This was reported by urban water utilities, rural water service providers, rural communities and private industries that were accessing water from government water supplies. Households reported accessing water from multiple sources and those located further from waterpoints had to spend more time travelling to access water.

> "We travel around to many different sources to find water... During the dry season it is more difficult because we have to bring water for the cattle as well. In the dry season the distance is further. Often, we go at night to collect water. We don't know which sources will be available... There are times when there is no water and we come back with an empty barrel and we are thirsty. It happens at some point every year."

(Male farmer, upper Awash basin, December 2018)

Inequities between water user groups

With our research, we explored the inequity of water security between different water user groups. Groundwater development is driven more by private investment (industrialization, flower farms) than human needs. Figure 10 shows how a small number of boreholes are dedicated to urban water supply compared to the total number of boreholes in the Upper Awash basin.

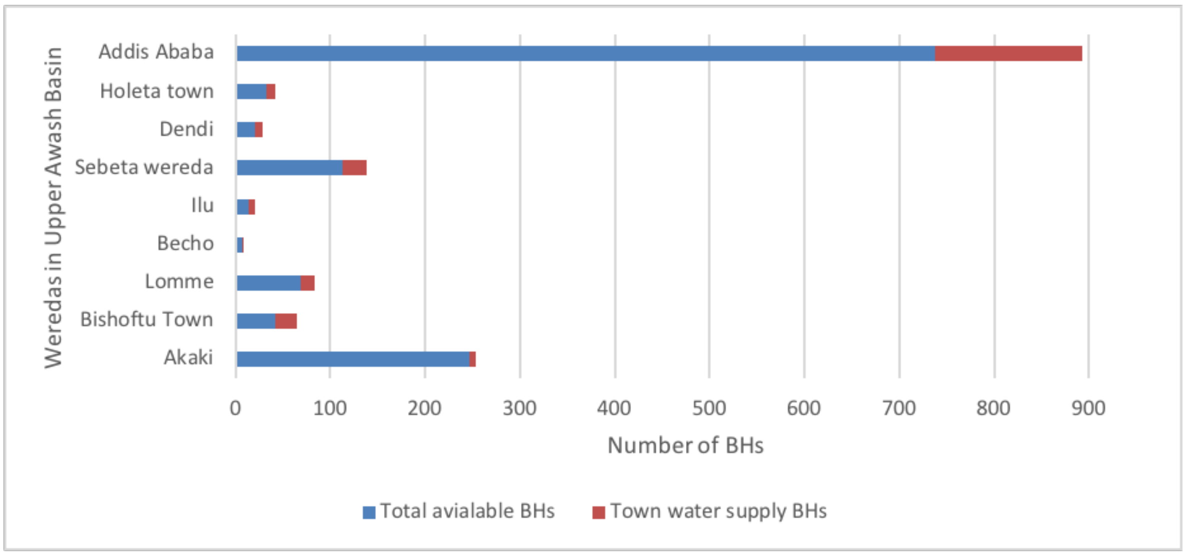


Figure 10. Comparison of available boreholes dedicated for urban water supply with total number of boreholes in the Upper Awash basin.

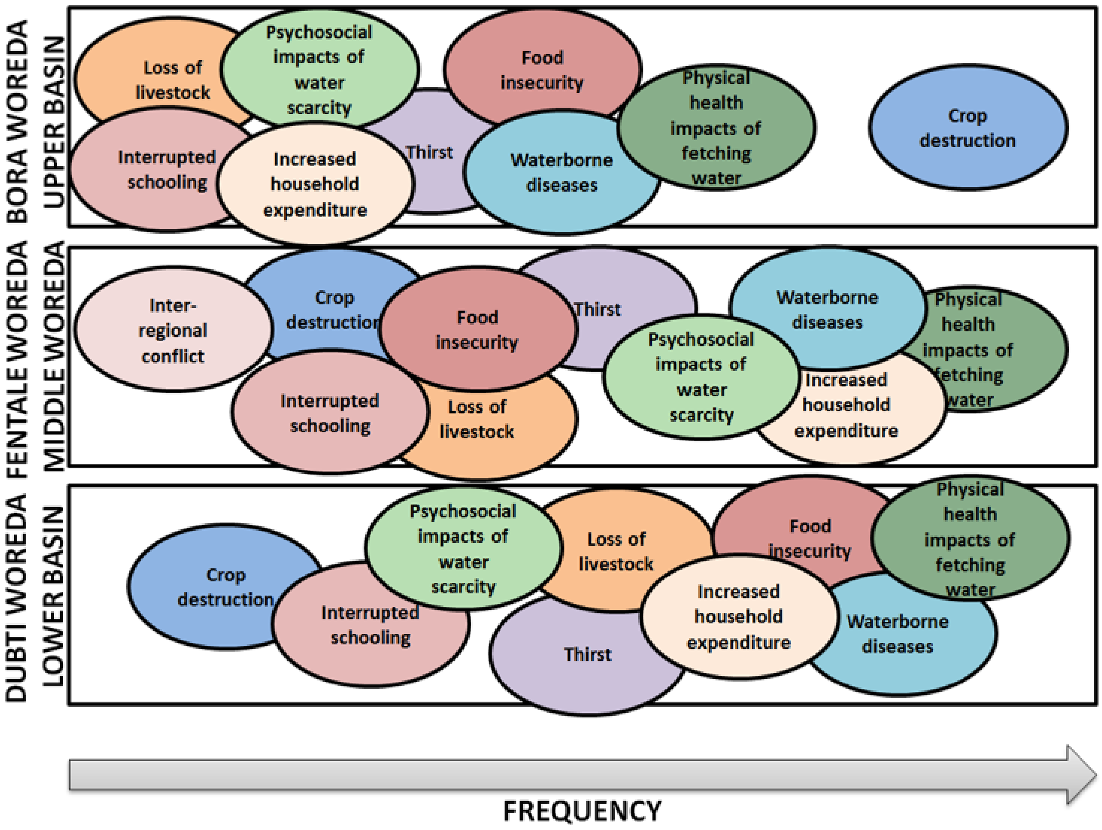


Figure 11. Difference in experiences of water-related risks by rural communities across the basin

Upstream-downstream inequities

In the arid downstream, rural dwellers were experiencing water scarcity most of the year. The average annual rainfall in the study site was around 200mm. In this district, women and men reported travelling up to 10 hours to fetch water for domestic use at certain times of the year. These downstream communities were experiencing far greater health risks from water fetching than those upstream – reporting extreme fatigue, thirst and physical pain.

Gendered inequalities within communities

Men, women and children are affected in different ways by water insecurity. We found that men experienced the emotional burden of being the household 'provider' when climate shocks resulted in crop destruction or loss of livestock. Male informants reported feeling 'disturbed' and 'great worry'. Women are primarily responsible for managing household water and their workload greatly increases during floods and droughts. Children were vulnerable to multiple risks and often parents were burdened with deciding how best to protect their children during climate shocks.

Socio-cultural drivers of inequities

Culturally defined gender roles in Ethiopia contribute to how water security is unequal between men, women and children.
It is important that this is taken into consideration when seeking to address unequal water insecurity.

Less wealthy water users face greater challenges in becoming water secure. Within communities, this means that households more affected by poverty have worse access to water. Across the basin, we find that private companies with high capacity for investment have better water access.

Institutional drivers of inequities

Water allocation decisions are difficult in a basin with different water users and development priorities. The national water policy mandates that drinking water is the highest investment priority. Water allocation for irrigation, particularly for the state-owned sugarcane farms is a high priority for water allocation planning in the Awash basin due to their important role in the national economy. Juggling demand between these sectors results in inequities.

Water pricing in the basin is highly inequitable. Industrial water users pay 3ETB/1000m^3 of (untreated) water that they use. (0.0001 USD/m^3) whereas a rural household pays 0.5 ETB/20l of (untreated) water that they use (0.87 USD/m^3). It is important to note that, industrial water users do incur their own infrastructure development and maintenance costs but this does not negate that fact that rural households are paying 8700 times more for access to water.

Biophysical drivers of inequities

Exposure to water risks from flood and drought and access to safe reliable drinking water are driven, in part, by location in the basin. This is because of the proximity of water managers to available water resources and the quality of those resources as well as the climate conditions. This means that water security requires multiple interventions at different scales.

There are different climate stories across the basin (Figure 12). We have examined the climates of three woredas in the upper, middle, and lower parts of the basin. In Dubti, in the lower basin, rainfall rates during the two rainy seasons (March-May and July-September) are highly variable, while the near zero rain rates in June are not variable. Fentale, in the middle-basin has a similar bimodal rainfall climatology, but

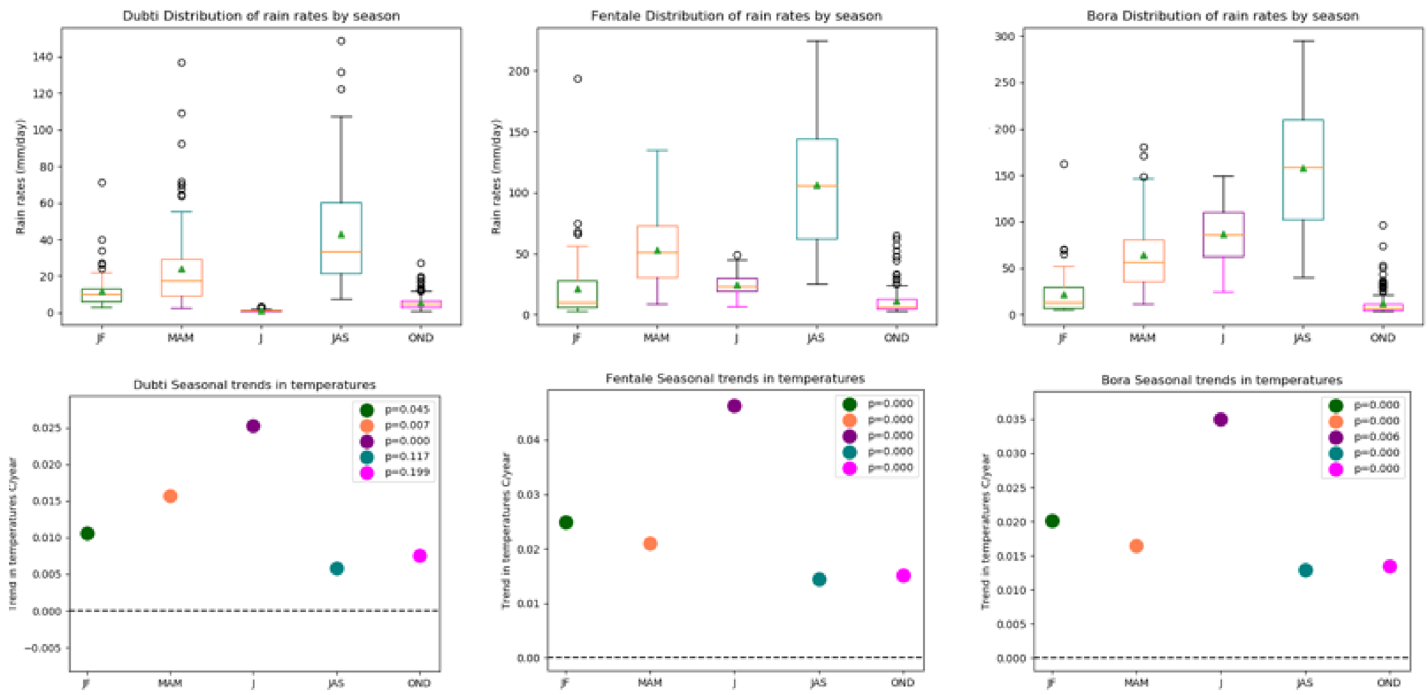


Figure 12. Distributions of seasonal rain rates (mm/day) showing the seasonal climatology of rainfall in three woredas in the Awash basin, using the merged gauge and satellite rainfall dataset CHIRPS2.0 from 1981-2018 (top row). Linear temperature trends (C/year) for the same woredas from 1981-2018 using the ERA5 reanalysis from the ECMWF (bottom row).

has less variable rain rates during the two rainy seasons. Contrasting these with Bora in the upper basin, the rainfall climatology is unimodal (having a different scale of rainfall) with dry periods only from October-February.

Land-cover change from the expanding Lake Beseka varied across the basin and also within woredas, according to place. In the middle basin, the expanding lake Beseka was covering land, limiting land-based livelihoods. Moreover, the lake was expanding to cover the urban water supply infrastructure for Metehara town, the capital urban area of Fentale woreda. This was resulting in challenges for the urban water utility to deliver safe and reliable water supplies to urban dwellers.

KEY FINDINGS

- Across seven urban water utilities, all reported intermittent access to water, mostly due to infrastructure failure or a lack of electricity.
- In most rural and urban cases, water was not being treated before being distributed to community members, despite dangerously high levels of contaminants including fluoride, and unknown levels of pathogens.
- Across water users in the basin, we found that private industrial water users enjoy high levels of water security and rural communities are the least water secure.
- There is considerable unequal development of groundwater resources in the Upper Awash basin.
- There are socio-cultural, institutional and biophysical drivers of inequities in water security in the Awash.

POLICY NOTE

It is important to ensure that the costs and benefits of water access are equitably distributed between private, public and community water users and that this is explicitly addressed in policy.

Research Outputs

Korzenevica, M., 2019. Emerging themes on considering water equity. *REACH Research Brief*.

Grasham, C. and Charles, K. *in review in Water Alternatives* Embedding risk and emphasising natural systems in hydrosocial studies.

Towards establishing a 'risk threshold' in the Awash river basin, Ethiopia. Dr Catherine Grasham, REACH Blog, July 2018

5. Land degradation and water security

Land degradation due to soil erosion is widespread in the Awash River basin. This is evident from constraints placed on the operation of various irrigation canals and the rapid decline of reservoir storage capacity, such as that of Koka dam. Researchers in the REACH programme have been working to understand and model sediment loads in the Awash River with a view to understanding potential policy interventions.

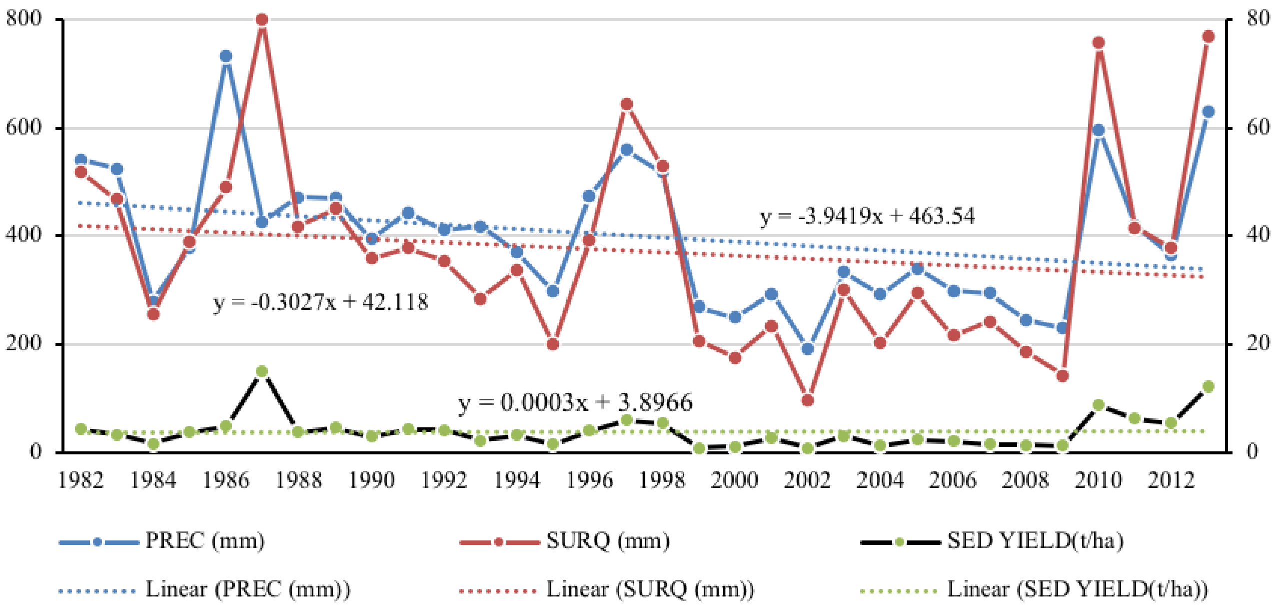


Figure 13. Inter-annual variability of precipitation, surface runoff and sediment outflow in the Awash river

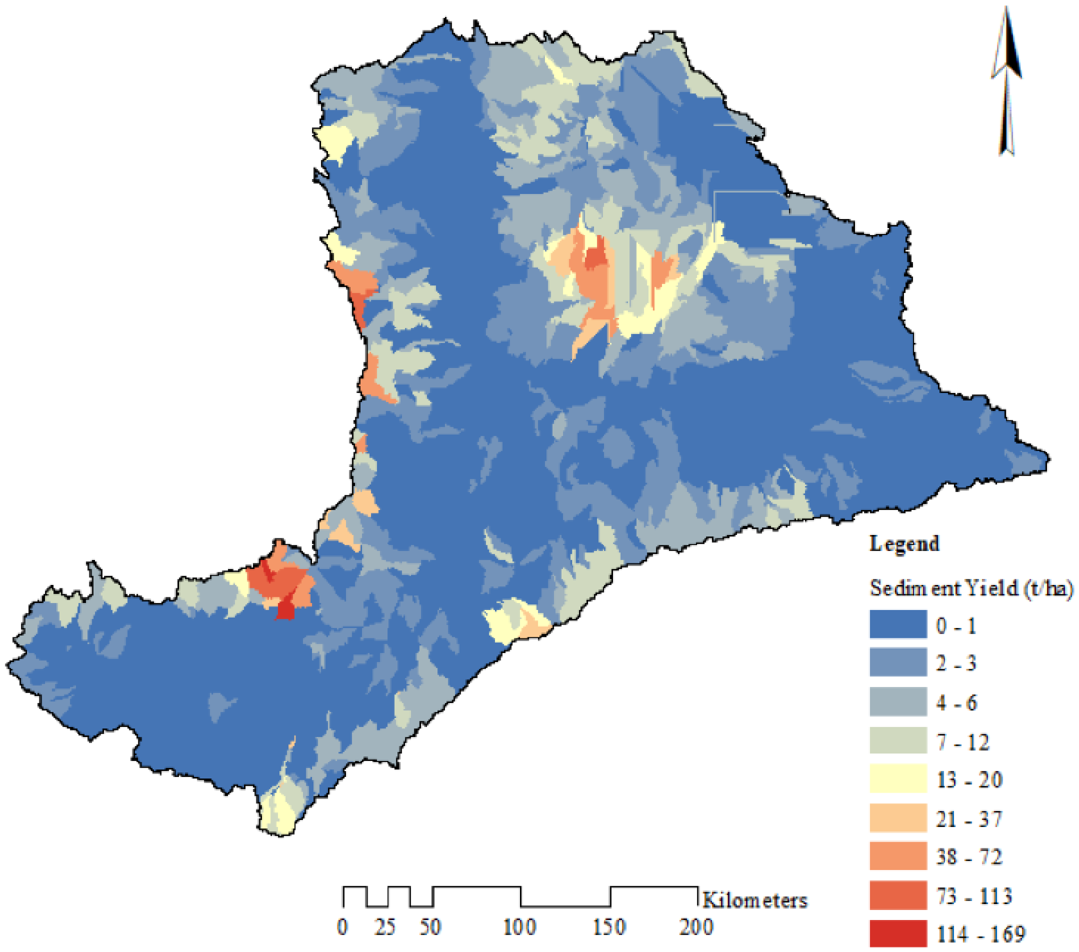


Figure 14. Sediment yield distribution over the Awash river sub-basins

KEY FINDINGS

- There is a strong relationship between inter-annual variability of precipitation, surface runoff and sediment outflow in the basin as shown in Figure 13.
- The weighted average annual basin specific sediment loading, calculated using MUSLE (modified universal soil loss equation) over a 33-year simulation period, was 4 tonnes/hectare/year.
- Sediment load in the Awash River varies across the basin (Figure 14.) and that from the highlands is particularly problematic.
- There is over 44 million tons of soil in the river course deposited in reservoirs, wetlands, riverbanks and irrigation canals.
- This value ranges from very high (169 t/ha/yr) in areas with slopes over 50 percent and annual rainfall of over 1000 mm, to negligible erosion in much of the lowlands where slope is flat and rainfall is low.
- The weighted average rate of soil erosion is highest (8 t/ha/yr) in degraded landscapes which account 39 percent of the land use/land cover in the basin.

POLICY NOTE

Efforts towards the rehabilitation of degraded landscapes, particularly in steep slope areas where the rate of soil erosion is in excess of the tolerable limit, is vital for improving water security.

Reserach Output

Edward, K., Mekonnen, D., Tiruneh, S. and Ringer, C. 2019. Sustainable Land Management and its Effects on Water Security and Poverty Evidence from a Watershed Intervention Program in Ethiopia. *IFPRI Discussion Paper 01811*. IFPRI (International Food Policy Research Institute).

6. Understanding water quality dynamics

Water quality is a key attribute of water resource systems. Water of good quality is essential for people, livestock and industry. The UN Sustainable Development Goal 6.3 aims to improve water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals to halve the proportion of untreated wastewater.

Water quality in watersheds is directly affected by vegetative cover, agricultural, and other land management practices, as well as basin-wide discharges of urban, industrial and rural waste. The basin's water resources are vulnerable to industrial and domestic waste discharge. Additionally, solid waste dumped in open spaces often ends up in rivers during storm runoff.

Background of Water Quality in the Awash

The dynamics of water quality in the Awash River basin are complex as chemistry derives from the geology and soils of the river basin as well as pollutants entering the river from diffuse agricultural sources as well as point sources from industry or domestic waste.

Aquifers in and around the city of Addis Ababa are showing signs of increasing contamination by chemicals, including nitrate, and there is an increasing concentration of heavy metal pollution, coliform and pathogen pollution in the water of Aba Samuel reservoir and its tributaries.

The Akaki River (upper basin) is the most polluted river due to the presence of industries and urban areas, with water quality worse than the permissible limits set by National Environmental Quality Standards.

There is a concern around the release of saline waters into the Awash river from natural saline springs or from irrigation water, particularly with regard to the expanding Lake Beseka. The lake water was highly saline in the 1960s having an EC value of about 71400μS/cm in 1961. Salinity levels have fallen since then, however, the water quality of Lake Beseka is not yet recommended for irrigation or drinking.

Using INCA to model water quality dynamics

In the REACH programme, we have been modelling water quality in the AWASH River system using the INCA suite of models

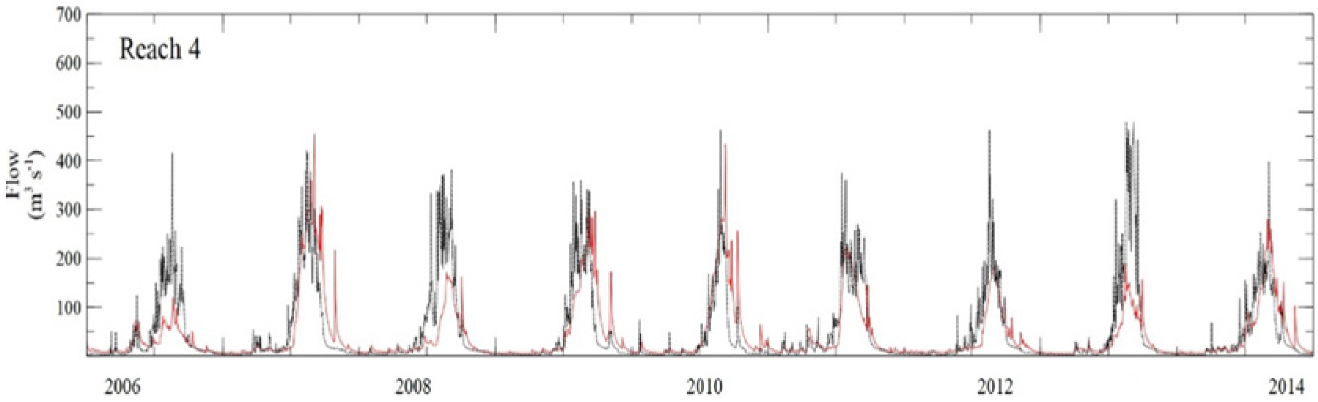


Figure 15. Flow simulation and observed flows along the AWASH at Reach 4 downstream of Addis Ababa from 2005-2014

to simulate the dynamics of river flow, nutrients (nitrate, ammonia, total and soluble phosphorus) and salinity. The INCA model is a process-based model which simulates the main processes related with rainfall-runoff transformation and the cycle and fate of several compounds, such as nitrate, ammonium and phosphorus. INCA gives high quality estimates of the diffuse sources of pollution and considers whole catchments using the processes to scale up from small to large catchments.

The nitrogen, phosphorus and sediments sub-models of INCA reproduce the water quality concentrations driven by the main sources (atmospheric deposition, fertilisers, runoff, wastewater, etc.) to the river. Two forms of nitrogen are considered as state variables: nitrate and ammonium. The most important soil processes are included, such as denitrification, nitrification, immobilisation, mineralisation and leaching towards the aquifer. Nitrification and denitrification processes in the streams are also taken into account. The phosphorus sub-model incorporates the main sources of phosphorus, both diffuse (fertilisers) and point (wastewater), as well as the main processes involving phosphorus, such as sorption/desorption. The phosphorus sub-model of the INCA model also includes the sediment equations.

Typical model simulations for the flow, nutrients and salinity are shown in Figures 15-17. The flows in Figure 15 show high flow conditions from June to September each year and these high flows will flush pollutants off the land's surface into the river system. For example, fertilizers applied to arable land and irrigation areas will runoff and create high runoff loads of nitrogen, phosphorus and ammonia in streams and rivers. However, in the low flow periods, the effluents from urban areas will be less diluted and hence concentrations will also rise.

Figure 16 shows the flows, soluble phosphorus and the total phosphorus as well as the peaks of phosphorus during the low flow periods. As with salinity (chlorine (Cl-)), the high concentrations of P also occur during the low flow periods. Figure 17 illustrates the build-up of salinity down the river system where the observed mean Cl- concentrations increased from 14 mg/L at Reach 5 to 45 mg/L at Reach 16, in the lower Awash. Other serious pollution problems in the Awash catchment are heavy metals downstream of tanneries, with high concentrations observed in the river system.

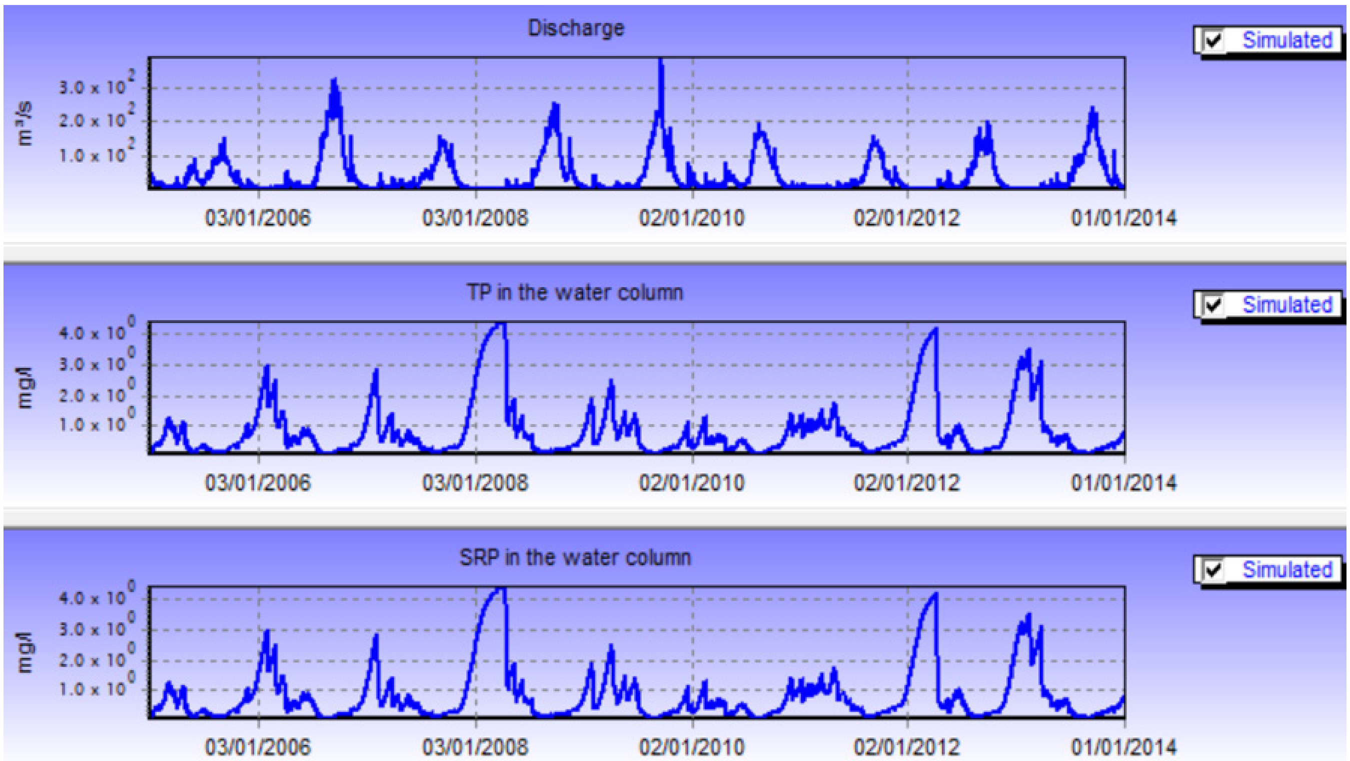


Figure 16. Flow and Phosphorus simulation along the Awash River below Addis Ababa from 2005-2014

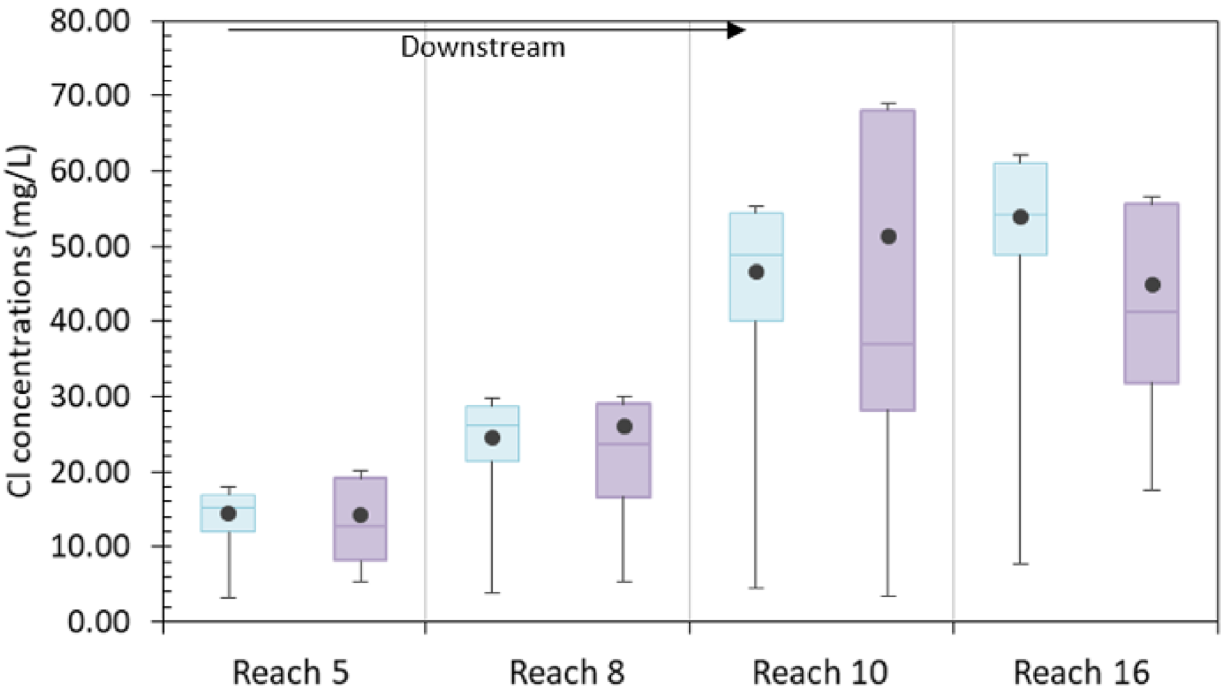


Figure 17. Comparison of modelled (blue) and observed (purple) chlorine concentrations at four reaches along the Awash River. The solid black dots show the mean concentrations of Cl- at each location

KEY FINDINGS

- There is a high flow season from June to September each year and this drives flushing of nutrients from the land into the river.
- In low flow periods, point sources dominate the water quality with peak values of nitrogen, ammonia, and phosphorus.
- With salinity (as simulated by chloride), the high concentrations also occur during the low flow periods, but the salinity builds up as the water moves down the river system.

POLICY NOTE

We recommend improved data sharing between stakeholders to ensure the ongoing management of water quality since multiple Ministries are involved in water quality data collection, regulation and management for both drinking water quality and pollution control.

Research Output

Yirma, Y. A. and Jin, L. 2020. Impact of Lake Beseka on the Water Quality of Awash River, Ethiopia. *American Journal of Water Resources,* 8 (1), 21-30

7. Collaborative water allocation and institutional clarity

Water scarcity has intensified the competition between water users in the Awash basin. Here we show how a basin-scale collaborative water allocation scheme can be used to improve water access for in the basin, increasing climate resilience for different sectors.

Collaborative water allocation

Organisations must work together and clearly understand their roles within the institutional make-up. The Awash is a transregional basin meaning that the overall responsibility for managing the river's waters is legally mandated to the federal Awash Basin Development Office (AwBDO). However, the regions have a constitutional right to develop water resources within their administrative boundaries. Therefore, responsibility for water resources management in the Awash basin is shared by government stakeholders at the federal and regional level, as well as at the local level.

Collaborative water allocation, where all water users are included in water allocation decisions, can improve water access and equity in the basin. As can be seen in Figure 18, there are surface water demand gaps. These gaps become wider during drought periods, highlighting the need for additional water sources such as groundwater.

During periods of water shortage limiting irrigation water abstraction to 75% improves water supply for several woredas in the middle and lower Awash (Figure 19). However, there are several woredas that may not benefit from the improved surface water allocation because they do not have physical access to the Awash River.

The constitutional and legal arrangements for managing water in the Awash demand

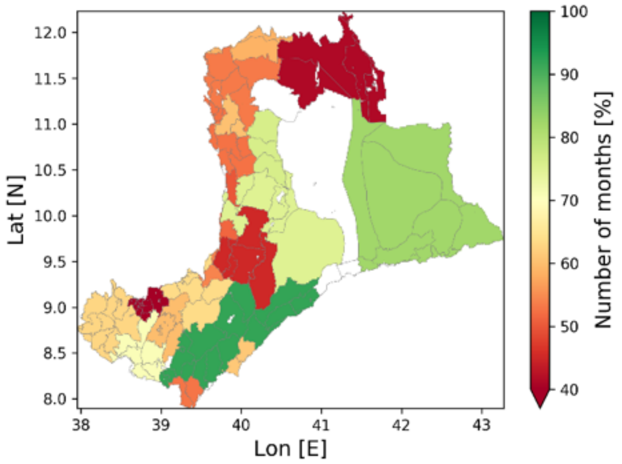


Figure 18. Total number of months (during 1983-2012) with at least 75% total water demand satisfied using surface water supply. (Groundwater data largely unavailable.)

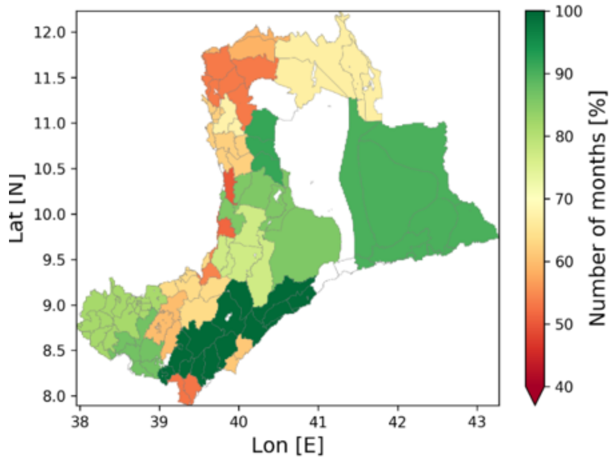


Figure 19.Water access can improve for several woredas (compared to Figure 18) by supplementing with groundwater sources and capping agricultural water use.

collaborative water allocation and institutional clarity. REACH research reveals that this is feasible and has identified 3 key areas for intervention in each case.

Institutional clarity

Broadly, we have found that federal and regional water managers have similar values and priorities for water resources development but there are barriers to co-ordination. In interviews with the AwBDO, Oromia and Afar regional Water, Mineral and Energy Bureaus, we found that shared values include: 1) good water quality; 2) successful management of floods and droughts and 3) safe water access for urban and rural communities.

There is a strong appetite for reduced industrial pollution as well as better flood and drought management across the basin. However, stakeholders and water users are unclear of their roles and responsibilities. We have found a lack of institutional clarity around roles and responsibilities for: 1) reducing industrial pollution, 2) drought management and 3) flood prevention.

KEY FINDINGS

- Surface water alone is not sufficient to meet current water demands in the Awash River basin.
- Crucially for industrial pollution, private companies were unsure of the wastewater treatment standards that they were required to meet.
- The AwBDO have a policy that in a drought year, irrigation upstream should be reduced to allow water to flow downstream to prevent drought risks across the basin. However, private, industrial water users reported not reducing their abstraction during drought years or being asked to do so.
- The main responsibility for drought preparedness and prevention institutionally lies in the Disaster Planning and Preparedness Commission. However, more can, and should, be done by water managers

to plan for water allocation during drought years.

- There is no clear, legal mandate for who is responsible for investing in flood mitigation resulting in inaction due to lack of allocated funding and collaboration

POLICY NOTE

To achieve water security, closer collaboration and greater institutional clarity is needed in 3 key areas: 1) protecting water quality; 2) successful management of floods and droughts and 3) safe water access for urban and rural communities.

8. Advancements in hydro-economics

Understanding hydro-economics in the Awash basin is critical for meeting sustainable growth targets. REACH researchers have explored the multi-sectoral and distributional economic impacts of rainfall shocks and the economic implications of irrigation and rainfed agriculture for smallholder farmers across the basin.

Macroeconomic impacts of three different climate scenarios

A Computable General Equilibrium (CGE) model was used to simulate how rainfall shocks propagate through the wider economy of the basin under three different climate change scenarios: 1) rainfall decrease, 2) rainfall increase and 3) spatial redistribution of rainfall.

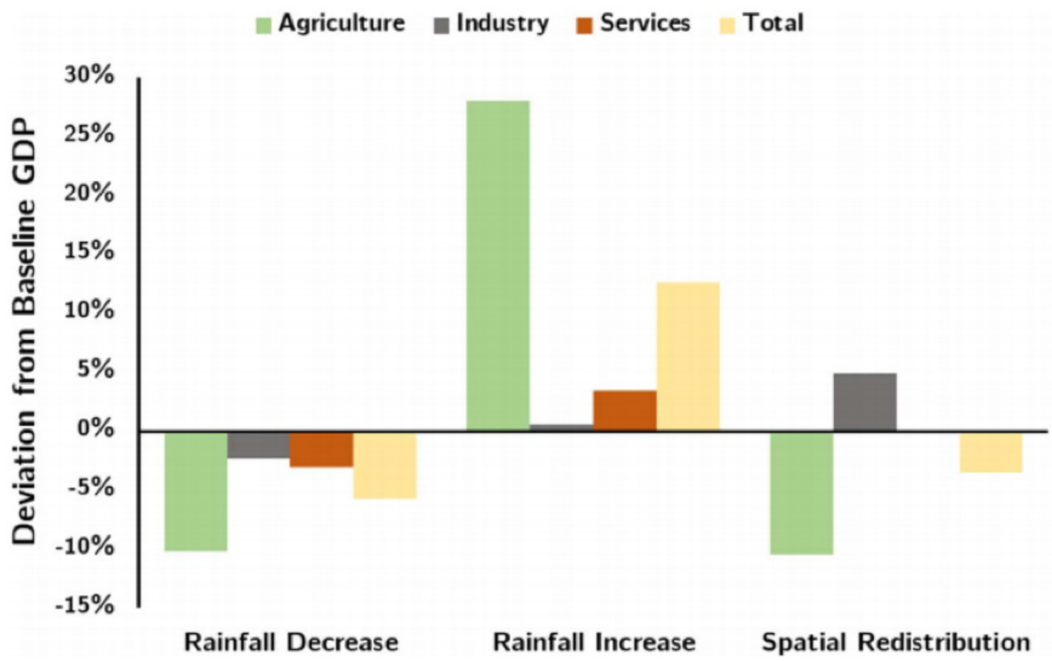


Figure 20. Macroeconomic impacts by sector of three different climate scenarios measured as deviations from the baseline GDP (2011–2015).

The Economics of Irrigation Water

An extensive household survey was conducted with farmers cultivating rainfed and irrigated small plots in five districts which are hotspots of smallholder agriculture in the basin: Akaki, Adama, Fentale, Amibara and Asaita (from upstream to downstream). This survey was conducted to explore the economics of irrigation water vis-à-vis rainfed agriculture.

POLICY NOTE

There are opportunities for improving economic efficiency in agriculture across the basin which is urgent given the likelihood of decreased future rainfall with climate change.

KEY FINDINGS

- The basin's economy and expanding agricultural sector are highly vulnerable to the impacts of rainfall shocks.
- A rainfall decrease scenario could lead to a 5% decline in the basin's GDP, with agricultural GDP standing to drop by as much as 10%.
- The economic returns from irrigation vary across the basin: the opportunity cost of water use in the lower part of the basin is higher than in the upper part of the basin since rainfed agriculture is hardly practiced in the former.
- Irrigation expansion must go hand-in-hand with investment in access to agricultural inputs as well as other livelihood options. Any investments in irrigation expansion must consider its ramifications in other parts of the basin.

Research Outputs

Borgomeo E., Vadheim B., Woldeyes F. B., Alamirew T., Tamru S., Charles K. J., Kebede S., Walker O. 2017. The distributional and multi-sectoral impacts of rainfall shocks: Evidence from computablen general equilibrium modelling for the Awash Basin, Ethiopia. *Ecological Economics*, 146, 621-632.

Vivid Economics. 2016. Water resources and extreme events in the Awash basin: economic effects and policy implications, *Report prepared for the Global Green Growth Institute*.

Too much, too little: the economic impacts of rainfall availability and variability on the Awash basin. Dr Tena Alimarew and Dr Edoardo Borgomeo, REACH Blog, January 2018.

Water-related extremes and economic shocks in Ethiopia. REACH Blog, August 2016.

FUTURE RESEARCH THEMES 2020-2024

Climate Resilience

Climate resilience can broadly be described as the ability to absorb stress, externally forced by a changing climate or variability and to adapt to this externally forced stress, in a sustainable way. In REACH, we have been working to understand how to strengthen climate resilience in the Awash.

We will continue interdisciplinary research and capacity building activities to move towards climate resilient water security in the basin. Understanding the historical and current climate can be useful anchors for building climate resilience within the basin. However, the information required to build climate resilience goes beyond the understanding of hazards.

Climate communication. Water managers in government and non-government organisations have developed deep expertise relevant for their roles through study, training and experience. However, these do not always include opportunities to integrate an understanding of climate and the likely impacts on the water systems they manage. Furthermore, barriers to the uptake of climate data and forecasts can vary from political restrictions on data use to presentation of data on scales and timeframes that do not match those required by the water manager. This research will seek to understand the needs of stakeholders in relation to climate data, forecasts and their application to their work. We will assess demand, barriers and incentives, considering modalities preferred for capacity building and communication that can increase climate communication in a sustained manner for stakeholders across water management institutions.

Water Quality

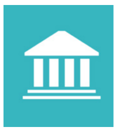
Improving water quality in the environment and for drinking is not a simple technical challenge, but a complex problem that includes aspects of science, politics, behaviour and planning. The water quality that people are exposed to is a result of range of factors, from the natural occurrence of contaminants and pollution sources, design and management of the water access infrastructure, and hygiene behaviour.

Sustainable pathways for urban and industrial growth. Expanding urban growth and industrial development are a growing threat to the provision of safe drinking water, and to ecosystems. Water managers often struggle with a lack of information on water quality hazards, due to limited resources for monitoring the range of potential threats. In this research, we will expand river, groundwater and wastewater monitoring, using results to inform modelling, highlighting sources of contamination and impact pathways to guide targeted policy and regulatory responses at different scales.

Inequalities

Inequalities in water security are often difficult to identify. REACH research has found that, in the Awash, inequalities in water security vary at the basin scale – from upstream to downstream – and within communities among men, women and children. We have also found multiple drivers for inequalities including socio-cultural, institutional and biophysical components.

Inclusive planning tools for water allocation. Scarcity of safe water is increasing as water demand and pollution increase. Drinking water may be, in many cases, the first priority for allocation, but our research has identified that tools to support this prioritisation are limited, based on rudimentary evaluations of demand. Small water users, such as smallholder farmers or small businesses, have difficulty engaging in the decision-making processes to influence the outcomes that could support their livelihoods. Ecological needs are often poorly understood. REACH will work with basin managers to support the development of decision tools that are inclusive and support their own needs. To do this, we will combine the perspectives and priorities of water users, from large industry to marginalised groups, based on social field research, with basin-scale climate and hydrological modelling.



Institutions

The governance of water security in the Awash basin is made up of a complex web of institutions. There are multiple stakeholders involved across different levels of government as well as NGOs, researchers and various water users. There are specific water policies and legal frameworks that determine how water security is governed.

Institutions to build water security sustainably at scale. Strong institutions are recognised by SDG 16 as a necessary condition to support sustainable development, protect vulnerable people and promote prosperity. Institutions govern how decisions, information, incentives and behaviour can promote or constrain water security outcomes for the poor. Without inclusive governance, reflecting the priorities of the poor, progress may remain inequitable in how water resources and services are managed, monitored, and allocated between competing demands by industry, agriculture, domestic water and ecosystems. REACH will explore how governments and researchers can collaborate to support institutional change in policy and practice.

Credit: Alice Chautard/REACH

RELEVANT REACH PUBLICATIONS

Grasham, C.F., Korzenevica, M. and Charles, K.J. 2019. On considering climate resilience in urban water security: a review of the vulnerability of the urban poor in sub-Saharan Africa. *WIREs Water*.

Theis, S., Bekele, R. D., Lefore, N., Meinzen-Dick, R. S. and Ringler, C. 2018 . Considering gender when promoting small-scale irrigation technologies: Guidance for inclusive irrigation interventions. International Food Policy Research Institute (IFPRI).

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van Koppen, B. and Schreiner, B. 2018. A hybrid approach to decolonize formal water law in Africa.*IWMI Research Report 173*, Colombo, Sri Lanka: International Water Management Institute (IWMI).

Walker, D., Haile, A.T., Gowing, J., Forsythe, N., and Parkin, G. 2019. Guideline: Selecting, training and managing para-hydrologists. *REACH Working Paper 6*, University of Oxford, Oxford, UK.

Walker, D., Haile, A. T., Gowing, J., Legesse, Y., Gebrehawariat, G., Hundie, H., Berhanu, D., and Parkin, G. 2019. Guideline: Community-based hydroclimate monitoring. *REACH Working Paper 5*, University of Oxford, Oxford, UK.

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