International Water Management Institute

Technical Brief

Identification of suitable sustainable agricultural intensification options for the Central Rift Valley, Ethiopia: Developing a multidisciplinary methodology for the Meki sub-basin

Ethiopia has ambitious plans of expanding irrigation throughout the country to feed the growing population (FDRE 2011; NPC 2016). Due to population growth, landscapes in Ethiopia are facing increasing pressure from agriculture (e.g., Desta et al. 2020). The promotion of irrigation using shallow groundwater (Gowing et al. 2020; Tilahun et al. 2020) and better water-lifting mechanisms (Gebregziabher 2012, 2019; Loulseged et al. 2011) is helping farmers to shift from only rain-fed agricultural production to utilizing irrigation during dry seasons and/or as a supplementary water source in the main rainy season.

Lake Ziway, in the Central Rift Valley (CRV), and its basins, in particular, experienced the increased presence of large- and small-scale irrigation systems because of government policies that favor agriculture. These systems are decreasing upstream river flow and reducing the size of downstream Lake Abijata (Desta and Lemma 2017; Desta et al. 2020; Getnet et al. 2014; Goshime et al. 2019; Legesse and Ayenew 2006; Seyoum et al. 2015). However, in the upstream catchments of Lake Ziway Basin, communities are not yet utilizing irrigation to its full extent. If agricultural intensification is continuously promoted (e.g., as done by ATA 2020) during the coming decades and irrigation is likely to increase, how will this impact the hydrology of the basin?

The *Resilience and Sustainability through Small-scale Irrigation Intensification* project, led by the International Water Management Institute (IWMI), aims to assess sustainable agricultural intensification pathways through an interdisciplinary approach.

Harvesting of cabbage from an irrigated field in Koshe (between Ziway and Butajira), Ethiopia (*photo:* Dawit Mekonnen).

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Methodology

A multidisciplinary approach (Figure 1) is proposed to explore the impacts of interventions such as small-scale irrigation expansion in one of the sub-basins of CRV – Meki sub-basin (Figure 2). The approach estimates water availability in the basin by integrating surface water and groundwater modeling. This integrated hydrological model is then used to test scenarios of agricultural intensification options. The scenarios are developed through co-designing with communities and stakeholders within the basin. Future climate change scenarios will be used to understand the potential risks in water availability these communities could face. Communities will be surveyed to identify their current agricultural practices and future aspirations to provide information on current and future land and water use in the basin. The information obtained from communities and climate models will help to alter the input variables that are used to run the hydrological models. Water availability estimated from the scenarios will be compared with the baseline water availability in the basin. The change in water availability will inform options for agricultural intensification. An overview of agricultural activities in the CRV basin based on survey data obtained from Farm Africa is presented in Box 1.

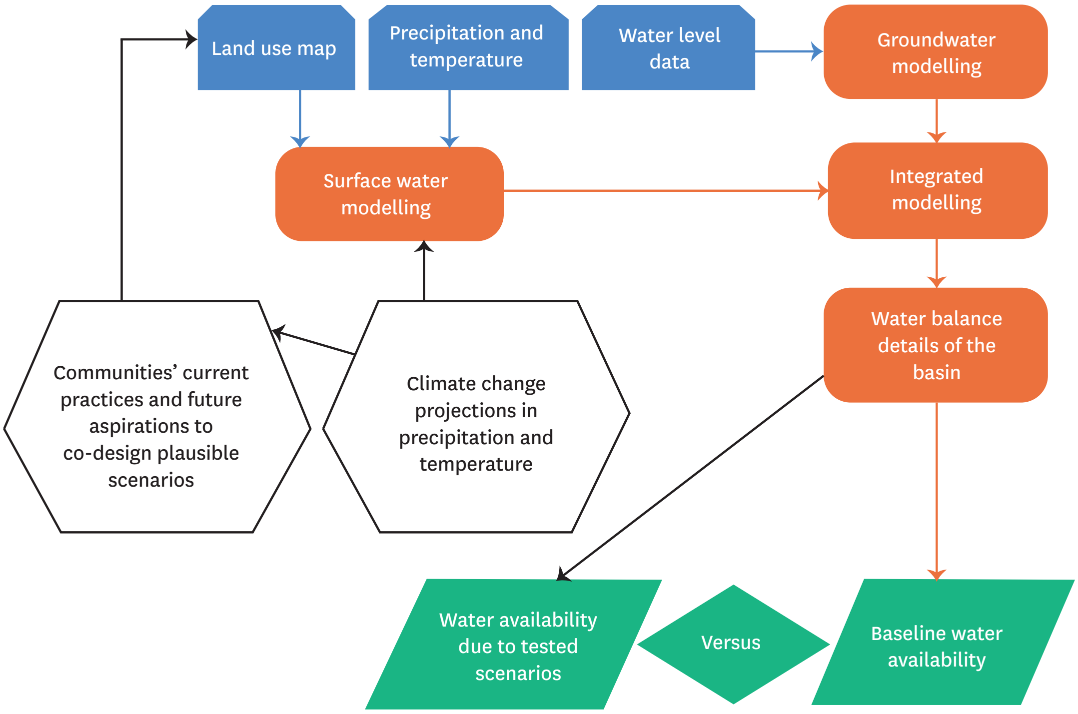

Figure 1. Flowchart showing the multidisciplinary approach used in the study through hydrological modelling and co-designing of scenarios.

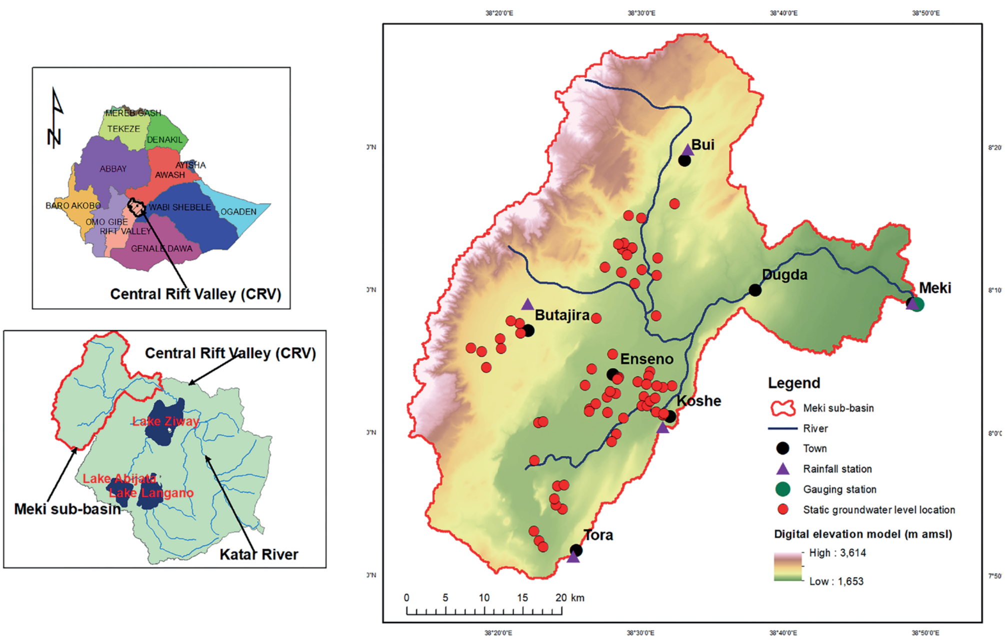

Figure 2. Maps of the Central Rift Valley in Ethiopia and the Meki sub-basin showing locations of rainfall and streamflow gauging stations, and groundwater wells where water levels are measured.

Note: m = meters; amsl = above mean sea level.

Box 1. Baseline situation of irrigation water source and shortage, irrigation technologies, and agrochemical use in the Central Rift Valley, Ethiopia.

Sustainable intensification (SI) indicators, identified from literature, fall into five domains: productivity, economic sustainability, environmental sustainability, social sustainability, and human well-being (Smith et al. 2017). Using Farm Africa's baseline survey 2018/2019 (Farm Africa 2020) in selected *woredas* (districts), an analysis was carried out to estimate some metrics of the environment, livelihoods, and irrigation production and their statistical associations in CRV to get a general picture of sustainable intensification (Musumba et al. 2017; Smith et al. 2017; USAID 2019). Following the guidelines provided by Musumba et al. (2017), we report some of the SI indicators based on the baseline survey.

Water resources and its use in irrigation

Rivers are the main source of irrigation water in CRV, followed by groundwater, lakes, and rainwater harvesting. Many households in Tiyo and Arsi Negele *woredas* (outside the boundary of Meki sub-basin) use rivers as a source of irrigation water. Groundwater is commonly used as an irrigation water source in Abijata Shalla (outside the boundary of Meki sub-basin) and Adami Tulu. Lake water is an important source of water in Adami Tulu and Meskan. Many households in Abijata Shalla (42%), Adami Tulu (31%) and Tiyo (22%) use rainwater harvesting as a source of irrigation water. Households practicing irrigated agricultural production in CRV, regardless of the source, lie between 14% and 31% in the selected districts.

Irrigation practices and perceptions on water shortages

Surface (flood) irrigation is the dominant practice in CRV, while the use of modern water application technologies (drip and sprinkler) is very low. This could be one of the reasons for inefficient water use (Koech and Langat 2018; Megersa and Abdulahi 2015) and probably the reason for the perceived water shortages. Nearly 65% of the households in Tiyo, 58% in Abijata Shalla, 32% in Arsi Negele, 13% in Meskan, and 1% in Adami Tulu use manual pumps to access both surface water and groundwater.

The perception of irrigation water shortages is used to identify whether water availability is assessed as being sufficient by households practicing irrigation. More than 50% of the households in Tiyo and Meskan, less than 35% in Arsi Negele, and about 13% in Adami Tulu perceive that there is sufficient irrigation water. None of the households in Abijata Shalla believe that there is sufficient water. Surprisingly, households that use water from rainwater harvesting and groundwater wells perceive that there is less water shortage compared to farmers that depend on lakes and rivers, perhaps highlighting household preference for private compared to collective management.

User of agrochemicals and potential water quality implications

Households use a variety of agrochemicals – herbicide, insecticide, fungicide, rodenticide, etc. – to protect their crops against weeds, pests and diseases, especially in vegetable cultivation, often at the expense of the environment and human health (Mengistie et al. 2017). Households in CRV use insecticide, herbicide, fungicide, rodenticide, and other chemicals (even those that are hazardous and have been phased out globally). More than 85% of the households report using agrochemicals. Chemicals such as Endosulfan, which has been phased out globally, are used in Adami Tulu and Arsi Negele. Dichlorodiphenyltrichloroethane (DDT), malathion, spiroxamine and diazinon are some of the chemicals that are used extensively in CRV, especially in Meskan, Arsi Negele and Tiyo *woredas*. This has serious implications for water quality, human health, and the goal of achieving sustainable agricultural intensification in CRV.

Integrated modelling of surface water and groundwater

Integrated models that account for surface water and groundwater interactions are useful for solving complex water resource problems and contribute substantially to our understanding of the impacts of land use change or agricultural intensification on the hydrology of watersheds. They are useful tools to develop conjunctive surface water and groundwater resource management plans, and to test water management scenarios that consider complex interactions of the hydrological system, particularly in a changing climate.

Conjunctive use of surface water and groundwater resources is essential in irrigated agriculture, because it can buffer the natural variability of surface water supply. To support conjunctive water use in the Meki sub-basin (catchment area of 2,183 km^2), an integrated model is developed using a coupled SWAT-MODFLOW model – Soil and Water Assessment Tool - Modular Three-Dimensional Finite Difference Groundwater Flow Model (SWAT-MODFLOW) (Bailey et al. 2016). SWAT is a widely applied, physically based, semi-distributed and continuous-time simulation hydrological model (Arnold et al. 1998), which has been applied in different small and large watersheds in Ethiopia and around the world. MODFLOW, on the other hand, is a three-dimensional, finite-difference hydrogeological model for simulating and predicting groundwater conditions and groundwater/surface water interactions (Harbaugh 2005). It is one of the industrial standard groundwater models developed by the United States Geological Survey (USGS). Although SWAT has its own groundwater module, it is a lumped model that cannot reflect a distributed concept. In the SWAT-MODFLOW coupling, the SWAT groundwater module is replaced by MODFLOW.

Pumping water using a diesel pump in an irrigation scheme near Ziway, Ethiopia (*photo:* Petterik Wiggers/IWMI).

The change in water budget obtained from the coupled SWAT-MODFLOW model provides a quantitative means to assess the effects of climate variability and changes as well as the impact of human activities on water resources. Some of the advantages of applying the SWAT-MODFLOW model in the Meki sub-basin include: (i) substantial contribution to our understanding of the hydrology of watersheds, rivers and aquifers. It provides a better conceptual understanding of the interconnectedness of the different hydrological processes; (ii) improved groundwater recharge estimation. As a critical component of the water balance, the groundwater recharge rate and its spatial and temporal variability are essential for groundwater sustainability; (iii) detailed groundwater–surface water interactions (spatiotemporal pattern of interactions) for different river reaches of the watershed, which will be looked at in different scenarios; (iv) detailed water budget in space and time for the catchment; (v) a credible platform for assessing the impact of climate change and other scenarios, due to the model's integrated system analysis approach that accounts for the nonlinear interactions between surface water and groundwater systems; and (vi) Identify data gaps in the integrated modelling approach and provide recommendations for future monitoring.

Climate change projections

Anticipated changes to hydrometeorological variables such as precipitation and temperature are estimated using climate models. Climate model data from Coupled Model Intercomparison Project Phase 6 (CMIP6), which are available from the Earth System Grid Federation (ESGF) website[1], are used. From the ESGF website, 25 models were downloaded with their historical and future projections. In the CMIP6, the scenarios are based on Shared Socioeconomic Pathways (SSPs), which are scenarios of projected socioeconomic global changes up to 2100 (O'Neill et al. 2014). For the Meki sub-basin, temperature projections show a continuous increase until mid-century. The projections for precipitation show increases in the range of 10%–40% for the March-May and July–September seasons, while a decrease up to 40% is projected for the October–December season. These projected changes will be used for estimating changes in water availability in the future, in conjunction with scenarios to be developed from communities' aspirations.

Co-designing of scenarios

Co-design is a collaborative approach to a design process that involves stakeholders providing a joint framing of objectives and challenges to ensure their needs are reflected in results and this helps to enhance uptake of the results (Mauser et al. 2013). It supports strategic planning and decision support by helping to balance the different and sometimes competing engagement demands and/or preferences from stakeholders (Kunseler et al. 2015). A scenario encompasses multiple types of hypothetical futures, which differ according to whether they inspire normative (what do we want to happen?), exploratory (what may happen?), or predictive (what will happen?) styles of thinking (van Notten et al. 2003).

For this study, we combined normative and explorative scenarios to explore the implications of short-term decision-making on a long-term future. Specifically, to inform the scenario development of agricultural intensification options, a participatory approach is used by consulting communities and

[1] https://esgf-node.llnl.gov/search/cmip6/

stakeholders of the Meki sub-basin. The participatory scenario development reflects how different agricultural intensification scenarios influence water security in three *woredas*[2] that are located in the upstream (Siltie *woreda*), mid-stream (Meskan *woreda*) and valley (Sodo *woreda*) of the sub-basin (Figure 3).

The scenario development with communities is guided by a semi-structured questionnaire that is divided into five modules. The aim of the first module is to understand typical household characteristics and livelihood activities. The aim of the second module is to understand the landscape of the study site in the past, present and future, using a landscape mapping exercise to facilitate discussion. The mapping exercise was carried out to obtain social data (i.e., perceptions or observations about a landscape) and arrange it spatially (Baker et al. 2015). This exercise helps to understand drivers and consequences of land use change (Hessel et al. 2009). Two *kebeles*[3] (one where livelihoods are dominated by irrigation, and rain-fed farming is commonly practiced in the other) from each *woreda* were identified in consultation with *woreda* officials. From each *kebele*, community members were identified based on their livelihood activity, gender and age. Separate discussions were held with community members (men, women and youth) from each *kebele*.

Key informant interviews were conducted with *woreda* officials (irrigation expert, livestock expert, *woreda* water expert, natural resource management expert) to inform scenario development. The interviews were guided by a semi-structured questionnaire that is divided into five modules that help to

Using groundwater for irrigation at a farm near Ziway, Ethiopia (*photo:* Apollo Habtamu/ILRI).

facilitate discussion and gain an understanding on: (i) water situation in *woredas*; (ii) water point information; (iii) water requirement for irrigation; (iv) water requirement for livestock; and (v) competition for water resources. Secondary data will also be collected from relevant government offices at national, regional, basin and *woreda* levels to gain a better understanding about agricultural intensification and the water situation in the study sites. The results will be analyzed through a coding process and used to support scenario development and co-design of sustainable intensification pathway options for the Meki sub-basin.

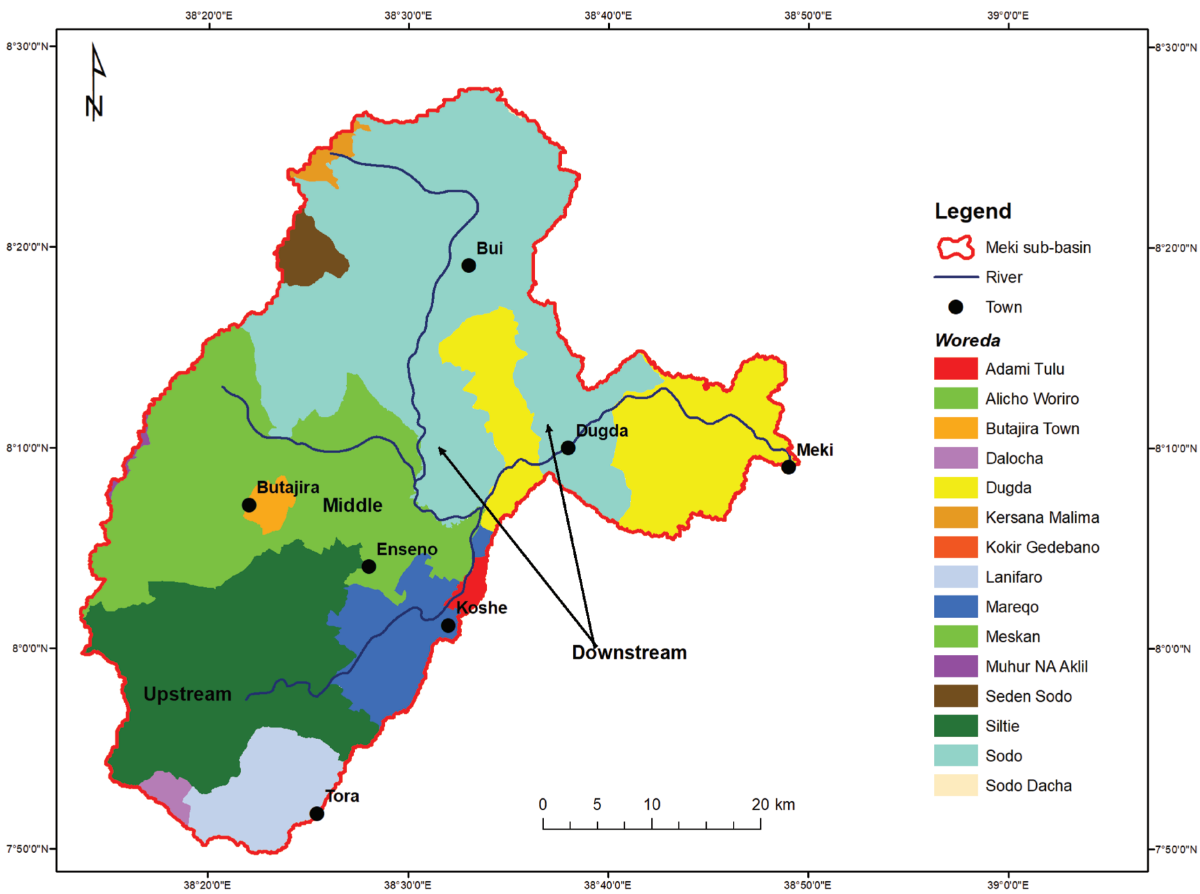

Figure 3. Map of *woredas* in Meki sub-basin.

[2] *Woreda* is the third-level administrative division of Ethiopia.
[3] *Kebele* is the smallest administrative unit of Ethiopia.

Next steps

This project demonstrates the usefulness of integrating biophysical and socioeconomic aspects in a given watershed to support the identification of suitable sustainable agricultural intensification options with limited impacts on the environment. The in-depth analysis for the Meki sub-basin shows that integration of groundwater modelling with surface water modelling provides a better representation of the groundwater component to understand water availability in the sub-basin. How communities will be able to intensify agricultural production through small-scale irrigation will be investigated in the next steps. This is supported by co-designing plausible scenarios in consultation with local communities and taking into account their future aspirations. In the project's next steps, the feasibility of agricultural intensification will be analyzed, and different water management options will be considered to support sustainability of the sub-basin.

Pumping groundwater from a private well near Meki, Ethiopia (*photo:* Apollo Habtamu/ILRI).

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A farmer using a wetting front detector near Meki, Ethiopia (*photo:* Apollo Habtamu/ILRI).

Project

The *Resilience and Sustainability through Small-scale Irrigation Intensification* project, led by the International Water Management Institute (IWMI), is conducted under Flagship 2: Land and Water Solutions for Sustainable Intensification (LWS) of the CGIAR Research Program on Water, Land and Ecosystems (WLE). The aim of the project is to assess sustainable agricultural intensification pathways through an interdisciplinary approach.

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