

Enhancing policy-relevant evidence for improving planning and management of smallholder irrigation, Ethiopia

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Front cover photo: Irrigated field of newly planted cabbage and growing green peeper from Lebu river in south Sodo (*Photo: Mulugeta Tadesse/IWMI*)

Back cover photo: Stakeholders' consultation workshop and policy dialogue participants in May 2026 (*Photo: Elizabeth Wamba/IWMI*)

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Summary

Irrigation is an important development pathway for strengthening food security, particularly as growing populations face increasing rainfall variability across seasons. In response, farmers in Ethiopia are expanding food production by using both surface water and groundwater for irrigation. However, as irrigation expands, the sustainability of these water resources may become a challenge if water use is not adequately monitored and managed. Effective management of surface and groundwater resources requires accurate information on the extent of land that should be irrigated and that is under irrigation in each season. Yet, such information is rarely captured with sufficient accuracy at local levels from field level monitoring. Using the Meki catchment in Ethiopia as a case study, this brief presents an approach for actual irrigated area mapping as policy-relevant evidence. It demonstrates the application of an improved approach that uses earth observation (EO) products in a context where ground-based data and information are fragmented. Ultimately, the brief outlines policy recommendations, highlighting how accurate irrigated area mapping can support improved water management and long-term development planning in Ethiopia.

Key messages

- Seasonal and fragmented irrigation practices make it difficult to accurately map smallholder irrigation in the Meki catchment, which can lead to an inaccurate estimate of the actual irrigated area.
- The methodological workflow applied in the Meki catchment uses multi-sensor and multi-temporal EO images to improve the detection of smallholder irrigation.
- The EO based approach applied in the Meki catchment can be used to validate district level reported irrigated area hectareage and provide reliable policy-relevant evidence for planning and management of resources for irrigation expansion.

Introduction

Ethiopia's development is highly linked to its water resources, particularly for growing food and energy generation. Irrigation is one of the key priorities in the government's development agenda according to the Ten-Year Perspective Development Plan (Planning and Development Commission, 2021). The challenges from erratic rainfall, seasonal shifts, frequent droughts and floods are driving smallholder farmers to consider irrigation as a way of adapting to the changing climate. Moreover, enhancing food security with multi-season production through irrigation and boosting their income in the process is gaining traction among smallholder farmers, especially for locations that are closer to market access. One of such locations is the Meki catchment, Central Rift Valley of Ethiopia, which is an area suitable for cash crops production such as fruits and vegetables during the dry season (Taye et al. 2026). The farmers in this catchment are aware of the benefits of irrigation as they are already using both surface and groundwater sources (Hulluka et al. 2024), and water pumps run on diesel or solar to expand dry season irrigation. This catchment is an example where rapid smallholder irrigation expansion is occurring concurrently to irrigation schemes developed by the government.

To improve planning and management of the expanding smallholder irrigation, up-to-date information is a key requirement, e.g., the amount of area under irrigation, the water source and availability for irrigation, where and when water deficit occurs in the catchment if any.

Among these important considerations, this brief focuses on the need to accurately estimate seasonal irrigated areas. Having accurate data and information on actual irrigated areas is critical for water management and long-term planning (Chandrasekharan et al. 2021). It helps determine how much irrigation development a basin can sustain and serves as a basic input for water balance and allocation models. Furthermore, the data helps establish the sustainability limit for resources use, such as groundwater abstraction thereby aiding conservation policies (Mohammed et al. 2023), and guiding infrastructure investment and planning.

However, the current challenge in Ethiopia is the lack of consensus on the irrigated area due to discrepancies (Haile and Kassa 2015) where the total area under irrigation is not well known (Gebul 2021). This lack of clarity is linked to the data source, assessment method, period of reporting, and different actors implementing irrigation and fragmented monitoring (Gebul 2021; Taye et al. 2024). There is also inconsistency in the definition of irrigated area when reported in different studies and government documents. In most cases, the confusion is caused because it is unclear whether reported numbers refer to the irrigation potential of a location, planned irrigation area for a given season, area equipped with irrigation facilities, or actual irrigated area in a specified time frame (Haile 2015; Chandrasekharan et al. 2021; Gebul 2021; GOPA 2026). At times, the actual irrigated area is estimated by adding together the areas reported across different production seasons from the same farmland (according to information from district experts). Given such ambiguous information and varying reports especially for smallholder irrigation, it is difficult to allocate, permit, or forecast water use in a basin without knowing how much land is actually under irrigation, its location and how it changes over time. This situation can also be a limiting factor in designing and implementing policies to efficiently manage water, energy, land, food production and environmental sustainability in basins like the Meki catchment.

This brief is based on a forthcoming publication (Tadesse et al., in submission) that proposed and implemented a methodology to map areas under irrigation in a given season using EO data that can work for both smallholder and large-scale irrigation. The methodology can help manage growing water use from surface and groundwater sources and their sustainability under ongoing irrigation expansion as well as the challenge of maintaining environmental flow in the Meki catchment. The brief argues that with current advancement in EO data, it is possible to accurately estimate irrigated areas in each season using remote sensing based spatial and temporal data. Dry-season irrigation is the focus of this study when irrigation is the dominant water source for food production in the Meki catchment. The remote sensing data collection was accompanied by ground truthing fieldwork in one of the woredas¹ (Misrak Meskan) where irrigation is massively implemented. This study advances previous efforts to map irrigated area for Ethiopia in general (e.g. Chandrasekharan et al. 2021), in the Awash basin (Gessesse et al. 2026), and in smaller watersheds in Bilate and Gumara (Yimer et al. 2024) with methodological improvement that is practical and scalable for regularly updating the information on actual irrigated areas in both smallholder and large-scale irrigation settings.

¹ woreda is the third-level administrative unit in Ethiopia, similar to a district. It is a local government unit.

Study area

The Meki catchment in the Central Rift Valley is located in the southern part of Ethiopia (Figure 1). It has a drainage area of 2183 km² with elevation ranging between 1653 m and 3614 m above mean sea level (Taye et al., 2022). The Gurage mountains form the western boundary of the catchment from which rivers originate and drain to the eastern flatlands (Legesse et al. 2010). Meki River is one of the main tributaries draining to Lake Ziway and its sustainable management has implications on the Lake ecosystem. The climate is semi-arid with average annual precipitation of 940 mm and the main rainy season between July and September. The long-term average minimum and maximum temperatures in the area are 12°C and 26°C, respectively.

Water availability in the Meki catchment is highly seasonal, rainfall fluctuates and surface water resources are often depleted in the dry periods (October to May) when agricultural demand peaks. During the dry season, irrigated agriculture produces cash crops, predominantly vegetables such as tomatoes, onions and cabbage, and fruit trees. Rainfed agriculture produces cereals (Taye et al., 2022). Both surface and groundwater sources are used for irrigation in the dry season as per their availability in different locations.

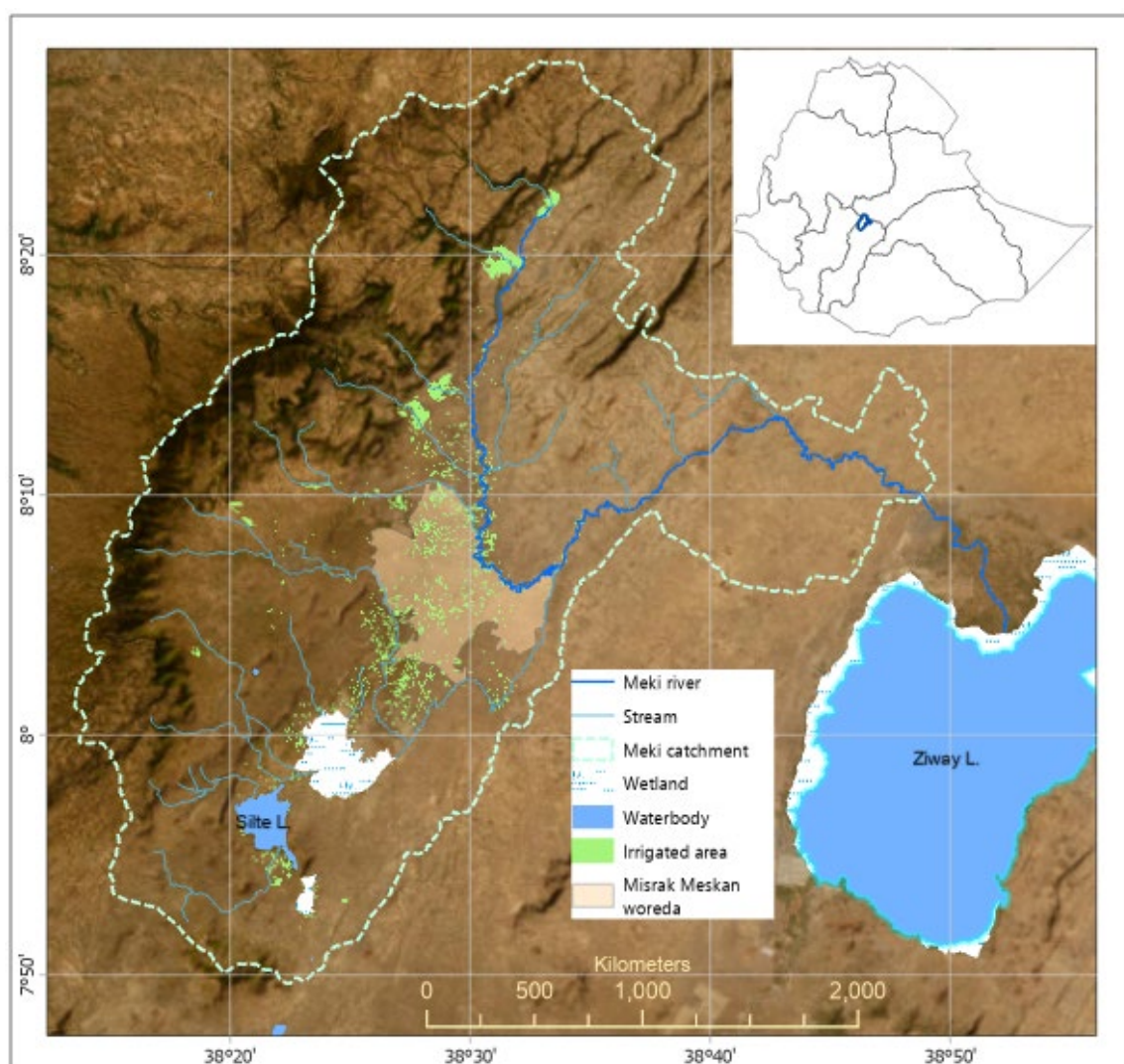


Figure 1. Location of Meki catchment in Ethiopia, irrigated areas of dry season during December 2024 to June 2025 (Source: Authors)

Methodology

The study by Tadesse et al. (in submission) integrates EO-based data analysis with field work-based validation. The EO-based data analysis includes land use and land cover (LULC) mapping, cropland masking and identification of irrigated areas based on training samples and machine learning algorithm. Additionally, consultations with various stakeholders were conducted in a series of meetings with woreda officials, partners, and policy dialogue workshops. The purpose of these consultations was to foster coordination among water, energy, food and environment sectors so that sustainable resource use is promoted while irrigation is expanding. It was also to validate the methods used to map irrigation area and estimate water availability in the catchment. Moreover, scientific literature was reviewed to understand current practices and policies on irrigation and water use.

The data sources for the remote-sensing based analysis are based on Sentinel-2 optical imagery, Sentinel-1 synthetic aperture radar (SAR), precipitation data from Climate Hazards Group InfraRed Precipitation with Station data- version 2, CHIRPS2 (Funk et al. 2021). Each dataset provided distinctive information. Sentinel-2 imagery characterizes vegetation development and surface moisture, while Sentinel-1 SAR contributes complementary observations of crop structure and surface conditions that are largely unaffected by cloud cover. CHIRPS precipitation data then supply the climatic context needed to separate crop responses driven by rainfall from those sustained by irrigation.

The LULC classification was conducted using the random forest machine learning method to map general cropland and filter out non-agricultural cover. Subsequently a Long Short-Term Memory (LSTM) neural network method was developed to capture temporal patterns in multitemporal satellite and precipitation data and to classify irrigation status at each observation period. The temporal scale for the analysis was monthly time step, and spatially the seasonal irrigation maps at 10-m resolution were produced. This data was validated using field-based ground truthing in Misrak Meskan woreda where irrigation is dominant. The fieldwork was conducted in eight Kebeles² (Figure 2) covering locations where irrigation is commonly practiced. The methodological framework that was followed in this study is given in Figure 3.

² The smallest administrative unit in Ethiopia, equivalent to a ward or local neighborhood/village authority.

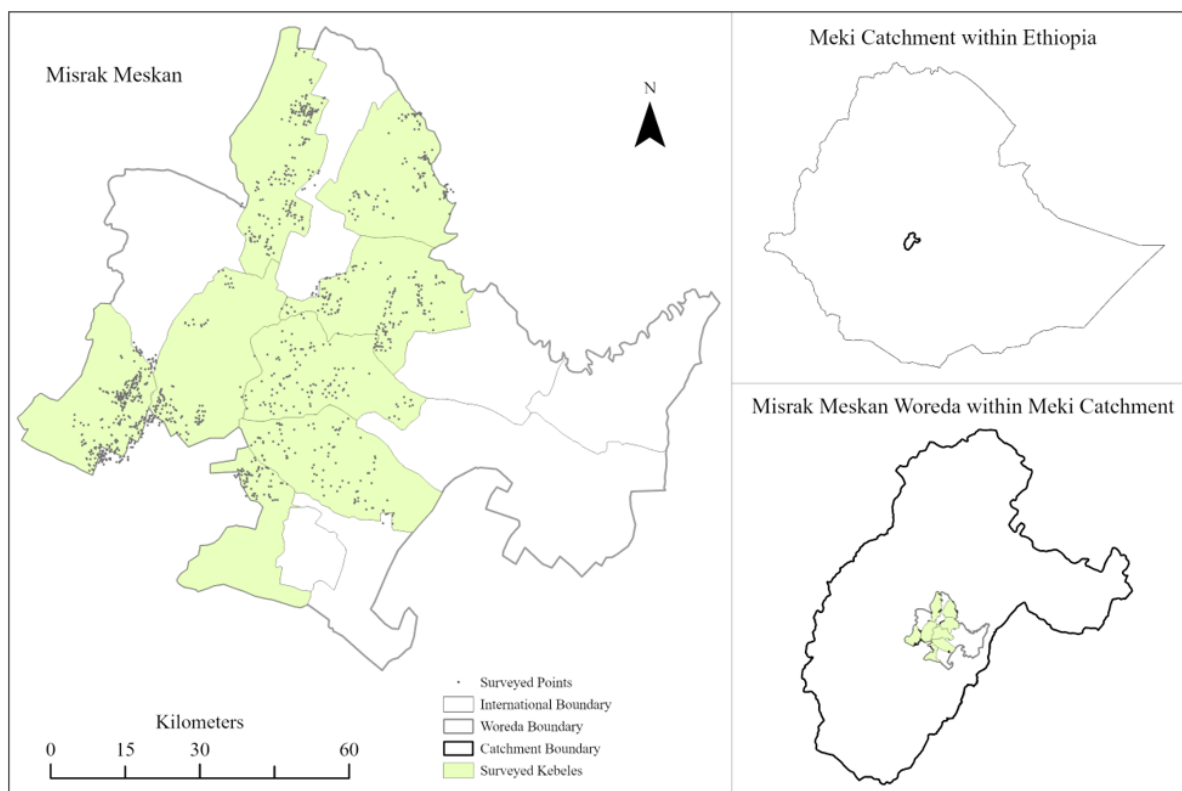


Figure 2. Location map of Misrak Meskan Woreda and eight kebeles (Bati Lejano, Bati Futo, Dobena Gola, Dobena Bati, Enseno Sme, Bamo, Yimerwacho 1, Yimerwacho 3) where fieldwork was conducted to validate remote sensing-based results (*Source: Authors*)

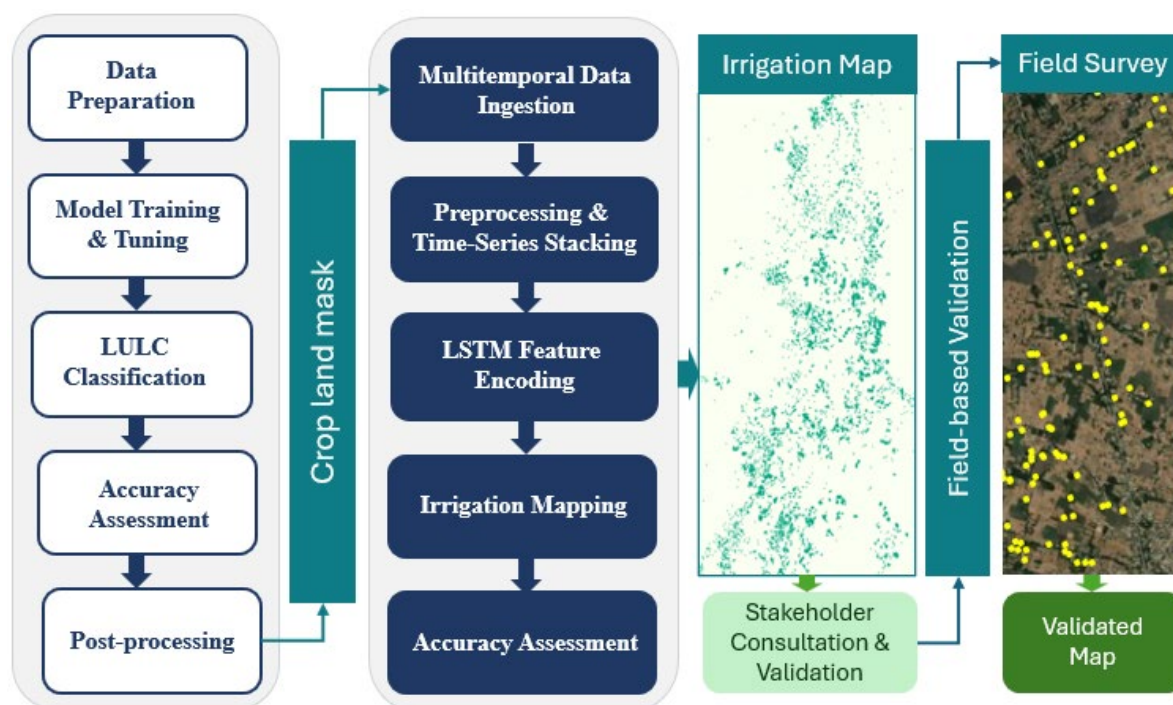


Figure 3. Methodological framework used in this study to map irrigated areas in the dry season of November 2024 – June 2025 (*Source: Authors*)

Key findings

Fragmented land and seasonal irrigation practices challenge accurate mapping of smallholder irrigated area

Smallholder irrigation in the Meki catchment is predominantly seasonal and intermittent, except in modern small-scale irrigation schemes, and is largely practiced during the dry season. During the irrigation season, farmers mainly cultivate vegetables, whereas the same fields are cultivated with cereal crops during the rainy season. The timing and extent of irrigation also vary according to farmers' access to water, irrigation pumps, fuel, agricultural inputs, and financial resources. This means farmland that is irrigated in one season may not be irrigated in the next, which indicates the highly dynamic nature of smallholder irrigation. Moreover, most smallholder farms lack permanent irrigation infrastructure, with field canals and land preparation established only during the irrigation season. These spatially fragmented and temporally dynamic practices create substantial challenges for identifying and mapping smallholder irrigated areas using a single time Normalized Difference Vegetation Index (NDVI) threshold-based approach, which doesn't have consistent irrigation seasons like large scale and/or modern irrigation schemes.

Multi-sensor and multi-temporal EO data have promising potential for accurate irrigated area estimation

In Ethiopia, the challenge of different studies estimating different actual irrigated area hectareage is a result of unclear and non-standardized methodology for their calculation among other technical, logistical and financial factors. The current advancement in earth observation data provides a good alternative to accurately estimate actual irrigated areas for a given season due to multi-temporal and high-resolution data availability. Different studies have used remote sensing data to map irrigated area in Ethiopia. Most are dependent on the NDVI and Enhanced Vegetation Index (EVI) with predefined threshold values that differentiate vegetation from non-vegetated area (Mohammed et al. 2023; Yimer et al. 2024). Such methods have limitations to capture the heterogeneous characteristics of smallholder irrigation, which is the focus of this brief.

The LSTM-based approach implemented in the Meki catchment integrates multi-sensor EO and climate information and is specifically designed to capture the spatial and temporal variability of smallholder irrigation. The method integrated optical, radar, and climate data that provided a stronger basis for irrigation discrimination than single-sensor approaches. Sentinel-2 captured vegetation dynamics, Sentinel-1 SAR provided complementary information on surface and moisture conditions, particularly under cloudy conditions and dense canopies, while CHIRPS precipitation helped distinguish irrigation-driven vegetation condition from rainfall-driven growth. The combined multi-sensor inputs enhanced the LSTM model's ability to distinguish irrigated areas from rainfed croplands and improved the reliability of irrigated area estimation.

In addition to the multi-sensor data, the use of an 8-month monthly sequence from November 2024 to June 2025 enabled the LSTM model to identify seasonal vegetation trajectories rather than relying on single-date spectral signatures, which is common in previous studies (Vogels et al., 2019; Mohammedshum et al., 2023).

District level reported irrigated area estimates and EO-based irrigated area estimates have differences caused by several factors

This study identified notable discrepancies between satellite-derived active irrigated areas and officially reported irrigation statistics. The EO-based analysis is focused on identifying total irrigated areas for the dry season from December 2024 to March 2025, a period with maximum irrigation, which resulted in 4460 ha/season in the Meki catchment (Figure 1). The estimated area is lower than the area reported in official statistics. This difference is expected and may be associated with differences in definition of irrigated areas and reporting practices. Local level reporting may focus on planned irrigation areas for the coming season, resulting in differences between command area-based estimates versus actively cultivated areas. Additionally, area estimation could be incorrect because of using local units of measurements that are approximate (e.g. 1 timad, which translates to approximately 0.25ha). Other differences can occur from scheme boundary differences and seasonal shifting of farmlands from year to year. Moreover, reported actual irrigated areas per year is commonly estimated as a cumulative production in different seasons from similar land area leading to double counting. Hence, it was found that locally reported irrigation areas often reflect the planned area rather than actual irrigated area in a given season.

The availability of EO therefore provides a valuable independent source of information for validating irrigation records for a given timeframe as data is available at frequent temporal steps. However, to implement this approach at a local level, there is a need to upgrade the technical capacity of local irrigation and water experts that plan and manage resources.

Key recommendations

The use of multi-sensor and multi-temporal EO is recommended to map fragmented smallholder irrigated farming

Mapping large-scale irrigation schemes using EO is a straightforward analysis since such schemes often have defined boundaries, infrastructure, and land-use patterns that are clearly visible in EO images. Conversely, smallholder irrigation, such as practiced in the Meki catchment, is more challenging to identify from EO images because the irrigated fields are fragmented, seasonal, and spatially dynamic. Monitoring through field surveys can be costly. For this reason, the multi-sensor and multi-temporal EO approach implemented in the Meki catchment is particularly valuable. It improves the detection of smallholder irrigated areas that are often missed by single-date imagery or fixed NDVI/EVI threshold-based methods commonly applied to large-scale irrigation schemes.

The time-series design enabled distinguishing irrigated fields from rainfed cropland by tracking seasonal vegetation trajectories, from decline of rainfed crops and the growth of irrigated crops. The use of high-resolution imagery improved the detection of small and dispersed plots. Hence, one of the recommendations stemming from this work is to apply EO-based methods applied in the Meki catchment in other areas since it is a scalable, repeatable, and operational approach. Irrigated maps produced through this methodological framework can support water accounting, irrigation monitoring, basin planning, and sustainable water-resource management.

The methodological workflow implemented in the Meki catchment is reproducible and scalable, making it suitable for use by practitioners

The current actual irrigated area estimates at a local level are conducted using simple approaches by surveying farmers' landholdings, a single time-based survey and/or NDVI based assessments as per consultations with government officials at different levels. This entails lack of standardized workflow for generating and disseminating accurate irrigated area estimates. The methodological workflow applied in the Meki catchment provides a standardized, end-to-end approach for mapping irrigated areas. The use of open-access datasets (such as Sentinel-1, Sentinel-2, and CHIRPS) and open-source Python tools make the approach reproducible, transferable, and suitable for local to basin-scale irrigated area monitoring.

While the methodological workflow developed in this study is reproducible and scalable and is recommended to be used by researchers as well as practitioners, due to the dynamic nature of smallholder irrigation, automatization of the system is recommended to support regular application in different contexts. Automatization would also make the approach easier for local level users to apply.

Institutional and human capacity development is needed at all levels

Irrigation development in Ethiopia faces multiple challenges such as building infrastructure without sustaining it or schemes operating below their design capacity (GOLA 2026), and insufficient planning and management of water needed for irrigation. One critical piece of information required to address these challenges is accurately estimating irrigated areas in each season. Current estimates rely mainly on field surveys, farmers' reported landholdings, and planned irrigation areas for the coming season. Estimating this area is constrained by financial, logistical, and technical challenges for both ground-based monitoring and the use of advanced approaches at local levels. Consultations with woreda-level experts, the Ministry of Irrigation and Lowlands (MILLs), and other partners indicate that local irrigation planners and managers often lack the technical capacity to apply advanced mapping methods.

There is a critical need to provide institutional and expert level capacity sharing to apply the methodological framework implemented in the Meki catchment. During the project time, IWMI provided capacity-strengthening training for stakeholders ranging from woreda experts to federal level personnel at different ministries. Similar training should continue to equip local experts with the skills needed for seasonal irrigation planning and management.

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