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192

Working Paper

Gap and Opportunity Analysis of Hydrological Monitoring in the Ziway-Shala Sub-basin, Ethiopia

Tabea Donauer, Alemseged Tamiru Haile, Demelash Wondimagegnehu Goshime, Tobias Siegfried and Silvan Ragettli

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Contents

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
AET	Actual Evapotranspiration
BDA	Basin Development Authority
CHIRP	Climate Hazards Group InfraRed Precipitation
CSV	Comma-separated Values
DAHITI	Database for Hydrological Time Series of Inland Waters
ET	Evapotranspiration
ETB	Ethiopian Birr
GLDAS	Global Land Data Assimilation System
GSM	Global System for Mobile Communications
iMoMo	Innovative Technologies for Monitoring, Modeling and Managing Water
IWMI	International Water Management Institute
METRIC	Mapping EvapoTranspiration at high Resolution using Internalized Calibration
MoWIE	Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
RVLB	Rift Valley Lakes Basin
RVLBA	Rift Valley Lakes Basin Authority
RVLBDO	Rift Valley Lakes Basin Development Office
SAWEL	Societal Development and Ecosystems Conservation in Sahelian Wetlands
SDC	Swiss Agency for Development and Cooperation
SWOT	Strengths, Weaknesses, Opportunities and Threats
USD	United States Dollar
WMO	World Meteorological Organization

Summary

This paper provides an overview of the current situation with regards to hydrological monitoring in the Ziway-Shala sub-basin in the Central Rift Valley of Ethiopia, including details of existing river and lake gauging stations in the sub-basin. The study aimed to analyze hydrological data collection by the Rift Valley Lakes Basin Development Office (RVLBDO), and gain a systematic understanding of data quality and availability. Interviews conducted with stakeholders revealed that insufficient budget allocation and attention to hydrological monitoring have led to severe deficiencies in the data collection process. Damaged gauging stations, outdated rating curves for most stations and the lack of capacity to digitize the data at the basin office are the main problems in the existing data collection process.

Assessment of the physical condition of 13 gauging stations highlighted that most stations are not properly maintained, with staff gauges often damaged by floods or vandalism at some sites, e.g., the station Meki at Meki Village. Interviews were conducted with local observers who are responsible for recording water level data at the gauging stations. Even though their salaries are low, observers are generally motivated and they have all received sufficient training to accomplish their tasks. However, some observers stated that they can report false data without being detected, due to the lack of supervision and cross-checking of data collected.

The hydrological technician at the main basin office in Hawassa has confirmed that the frequency of velocity measurements has decreased, which implies that rating curves to convert water level to discharge data have not been updated for several years. Water level data are currently available only in printed form at the RVLBDO in Hawassa, and there is a complete lack of responsibility and motivation for data digitization. Recommendations have been put forward in this paper to (i) improve the physical condition of gauging sites, (ii) immediately convert water data from printed copy to electronic copy and then to discharge data, and (iii) enhance data quality and sharing.

Opportunities for novel, non-traditional hydrological monitoring are also presented, with their applicability and benefit to complement traditional data collection in the Ziway-Shala sub-basin. Remote sensing technologies can be effectively used to fill existing data gaps (e.g., precipitation data), but require calibration and validation with ground data. Community-based (e.g., using the citizen science approach) monitoring programs have the potential to complement traditional data collection.

Research and development projects can also assist in the generation of additional hydrological data to fill gaps. However, if external organizations are involved in data collection, this needs to be well coordinated with the RVLBDO. Uncoordinated action of different projects, as well as political and institutional instability could threaten the current monitoring system.

Gap and Opportunity Analysis of Hydrological Monitoring in the Ziway-Shala Sub-basin, Ethiopia

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Introduction

Many researchers and practitioners have highlighted the lack of high-quality hydrological data in Ethiopia. Most available data on streamflow in the Upper Blue Nile Basin cannot be used to calibrate and validate rainfall-runoff models (Haile et al. 2017). Similar issues have been reported from (i) the Omo-Gibe River Basin, where there is a lack of long-term data and missing records on streamflow (Jillo et al. 2017); and the Ziway-Shala sub-basin (Goshime et al. 2019). However, none of these studies investigated the source of errors that led to questions about the quality of the streamflow data.

There is disagreement between hydrological findings reported by different studies on the Ziway-Shala sub-basin, which is mainly caused by uncertain data. For instance, mean annual inflow reported using different methods and periods of data from gauged catchments of Lake Ziway varies between 614 Mm^3 and 664 Mm^3 (Goshime et al. 2020a; Ayenew 2004), which corresponds to a difference of 50 Mm^3 (8%). This can be considered as a significant difference because it is larger than the current level of water abstraction from the lake. According to various studies, lake outflow is between 157 Mm^3 and 185 Mm^3, whereas the difference for lake evaporation is between 774 Mm^3 and 890 Mm^3 (refer to the review by Goshime et al. 2020a). It is, therefore, essential to explore and address data quality issues in the Ziway-Shala sub-basin. Filling existing data gaps and exploring opportunities to improve hydrological monitoring can help to narrow differences in the values reported for water balance components in the Ziway-Shala sub-basin. In particular, accurate hydrological data are urgently needed due to the rapidly increasing demand for and use of irrigation water in this sub-basin, which is driven by individual farmers, investors and government policy to rapidly scale up export-oriented, intensive agriculture and manufacturing. Providing access to such data can, therefore, help to prepare proper water allocation plans for the sub-basin, and introduce limits on water abstraction to safeguard lake ecosystems.

Existing data gaps could be effectively filled by using new types of data, for example, from (i) airborne or satellite remote sensing, and/or (ii) community-based monitoring. However, data products such as satellite-based precipitation and evapotranspiration measurements often show significant bias, which necessitates calibration with local in-situ data (Haile et al. 2013; Gumindoga et al. 2019). Similarly, hydrological models that can be used for operational planning and management need to be properly calibrated with measured in-stream discharge data so that they reflect the real situation in the field.

The strategy for developing new data streams, i.e., from remote sensing and/or community-based monitoring, has to rely on a precise understanding of existing monitoring gaps in basins under consideration. In this paper, we report on the existing monitoring gaps and opportunities for novel, non-traditional monitoring for the Ziway-Shala sub-basin in Ethiopia.

Largely determined by the vagaries of the African monsoon, water scarcity in the Sahelian Zone regularly leads to food insecurity for millions of people in sub-Saharan Africa (Ararso et al. 2009). While a lot has been invested in irrigation infrastructure in the Sahel region, natural wetlands and the services they provide to riparian communities have frequently been overlooked (van Asten et al. 2004). Rivers, floodplains, inland deltas and lakes cover approximately 10% of the region and are essential for farmers, fisher communities and pastoralists, especially during dry years. In many places, these wetlands are increasingly suffering from degradation. Reasons that contribute to unsustainable and unregulated use include inadequate or absent governance mechanisms and increased water use (Wetlands International 2017). Climate change may aggravate this situation in the future (Faramarzi et al. 2013).

Basin-wide activities can impact wetlands. For example, agricultural activities on hillslopes can dramatically alter the hydrological regimes of rivers draining into the wetlands and convert them from perennial to seasonal rivers. Agricultural activities can also increase the level of nutrient and pollutant loads, and contribute to an eutrophication of the wetlands and impact biodiversity in an adverse way (Dixon and Wood 2003).

A new development and conservation project – Societal Development and Ecosystems Conservation in Sahelian Wetlands (SAWEL) – focuses on improving food security and nutrition in the Sahel region by helping to safeguard wetlands through ecologically sustainable agricultural water management. While this project – supported by the Swiss Agency for Development and Cooperation (SDC) – aims to create global outreach and learning, its initial focus is in Mali and Ethiopia. In Mali, two intervention sites were selected, i.e., the seasonal Lac Wegnia and Sourou wetlands. In Ethiopia, the focus is on the Ziway-Shala lake system in the Rift Valley Lakes Basin (RVLB).

As in other parts of the developing and transitioning world, one of the major challenges is the absence of a consistent monitoring system and the lack of in-situ quality-controlled measurements that can be readily accessed by the authorities and used in their decision-making processes, for example, in relation to irrigation development. Thus, developing a good understanding of the hydrological situation, its main drivers and future changes for the sites under consideration is very difficult. Yet, at the same time, this is a necessary precondition for sound and sustainable water resources planning and management.

The next section provides background information on this endorheic Ziway-Shala sub-basin. Strengths and weaknesses of the current data collection process were identified and are highlighted. Possibilities to support existing institutions as well as further opportunities to improve the monitoring situation are also discussed.

Finally, it should be emphasized that this paper focuses on the assessment of streamflow and lake level stations, and the corresponding data collection processes. Therefore, only the institutional responsibilities of the Rift Valley Lakes Basin Development Office (RVLBDO) are discussed, since meteorological data collection is not taken into consideration.

The Ziway-Shala Sub-basin

Climate

The topography of the Ziway-Shala sub-basin ranges from 1,500 to 4,200 meters above sea level (masl). Therefore, the climate in the sub-basin is highly dependent on elevation. It is generally cooler and wetter in the highlands, with semiarid conditions in the Central Rift Valley (Melesse et al. 2014). Figure 1 indicates that average mean monthly temperatures in the sub-basin remain relatively constant and within 16 to 20 °C throughout the year. These values are based on the Global Land Data Assimilation System (GLDAS) reanalysis product, which showed a slight underestimation when compared with the average mean monthly temperature values (10.8 and 26.6 °C) obtained from the average of data from multiple stations. However, the distribution of rainfall shows a distinct seasonality. The hydrological year can be divided into a dry season lasting from October to February, main rainy season from July to September and 'small rainy season' from March to June.

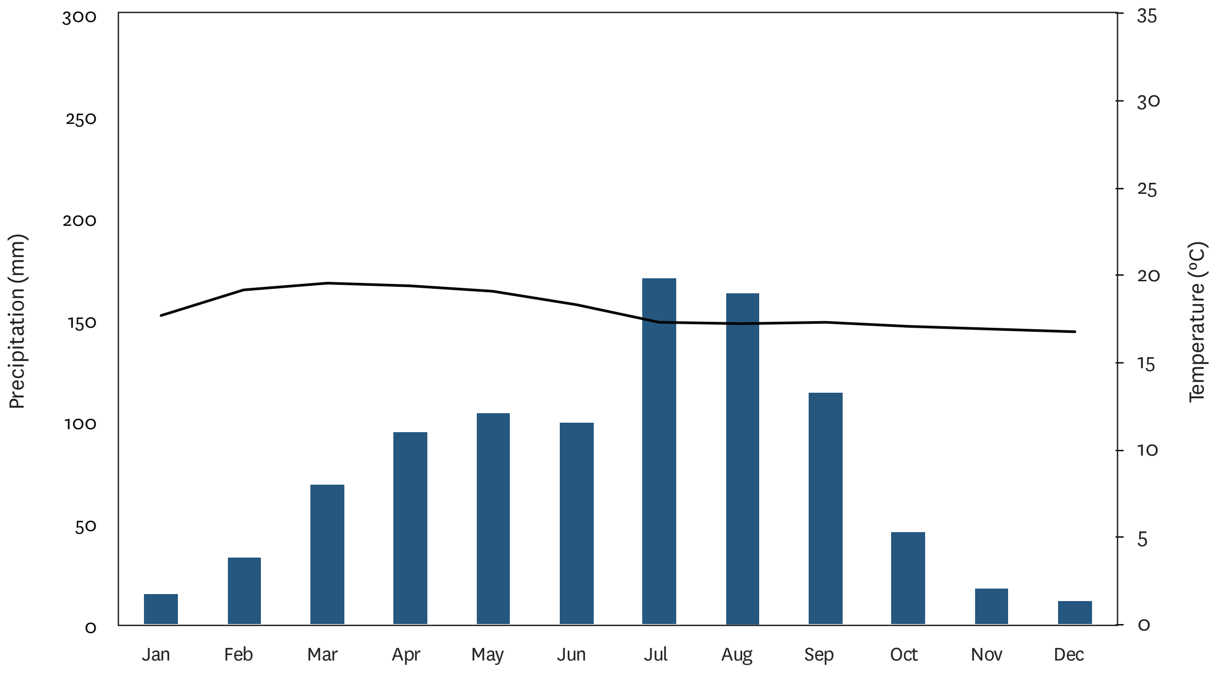


Figure 1. Climate in the Ziway-Shala sub-basin - monthly temperatures and sum of precipitation.

Notes: Gridded precipitation and temperature data were taken from the GLDAS product (grid scale: 0.25 °C) for the period between 1983 and 2019, and averaged over the Ziway-Shala sub-basin.

Precipitation records were obtained from 20 meteorological stations in Ziway-Shala and averaged over the basin. Long-term analysis shows that annual rainfall depth in the basin ranges between 700 and 1,100 mm. An extremely dry year was recorded in 2015, when average precipitation in the sub-basin was 479 mm. An insignificant (*at* significance level α = 0.05 using the Mann-Kendall trend test) decreasing trend was detected in annual rainfall between 1984 and 2018 (Figure 2). Long-term analysis of temperature data shows a moderately significant (*at* significance level α = 0.05 using the Mann-Kendall trend test) increasing trend during this time period (Figure 3).

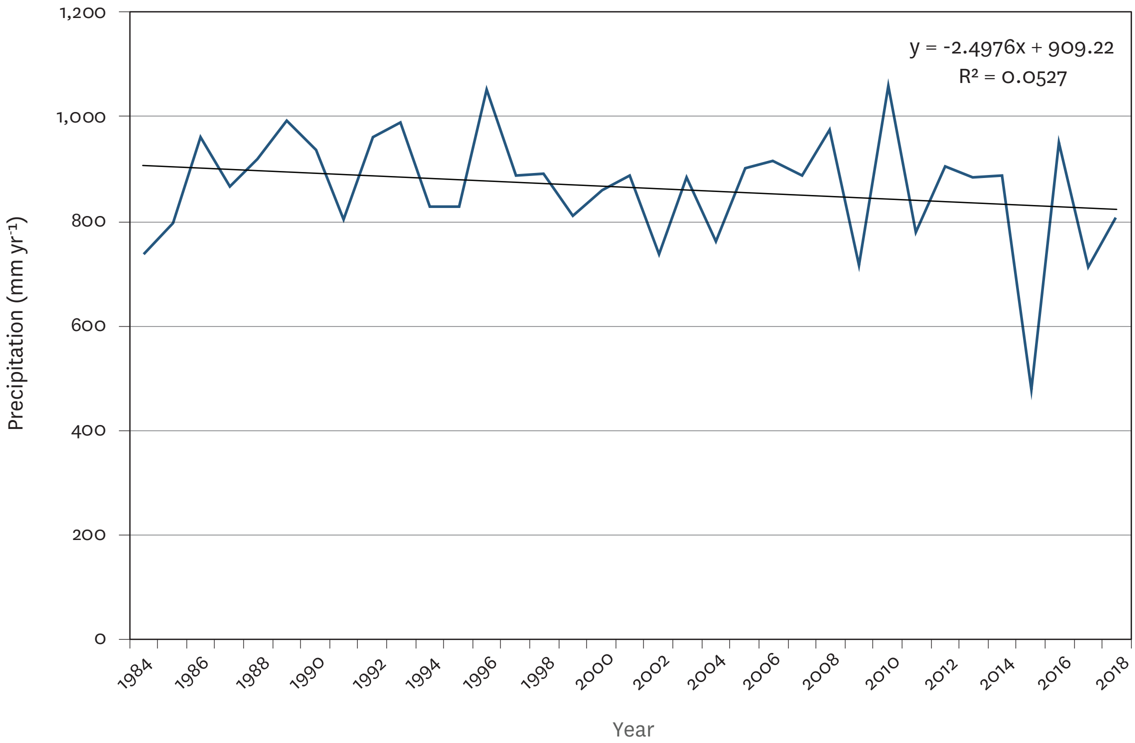


Figure 2. Long-term analysis of the annual precipitation amount in Ziway-Shala sub-basin.

Notes: Basin average gauge data from an ensemble of 20 meteorological stations were used. The dashed line indicates a decreasing trend in precipitation (insignificant - at significance level α = 0.05 using Mann-Kendall trend test).

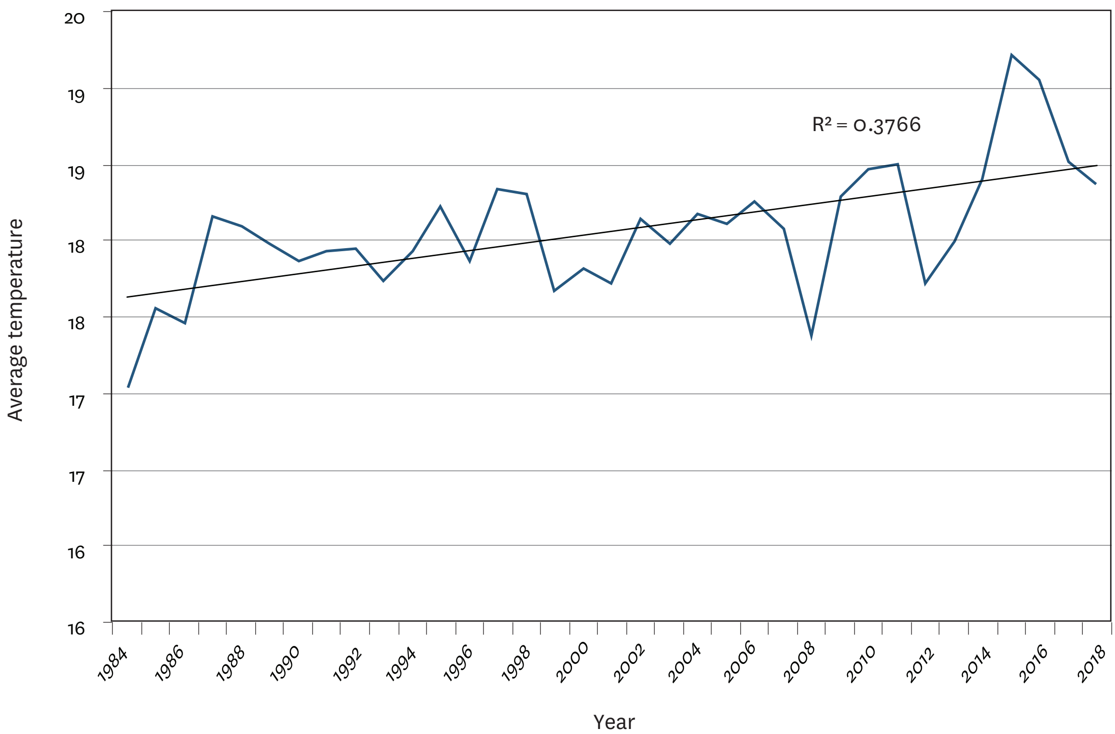


Figure 3. Long-term analysis of average annual temperature in Ziway-Shala sub-basin.

Notes: Basin average gauge data from an ensemble of 12 meteorological stations were used. The dashed line indicates an increasing trend in average annual temperature (moderately significant - at significance level α = 0.05 using Mann-Kendall trend test).

Hydrology

The Ziway-Shala sub-basin is situated in the Ethiopian Central Rift Valley and covers an area of approximately 15,000 km². As shown in Figure 4, it is a closed endorheic sub-basin, containing the four major lakes Ziway, Langano, Abijata and Shala. The three northern lakes (i.e., Ziway, Abijata and Langano) are connected by surface flows, while the southern Lake Shala is situated in a topographically separated sub-basin. Shala is connected to the lake system through groundwater flows from Lake Abijata (Le Turdu et al. 1999).

Lake Ziway is the only freshwater lake in the basin. It is mainly fed by the Katar and Meki rivers, which drain the highlands on the East and West of the Central Rift Valley, respectively (Hengsdijk and Jansen 2006). Based on simulated time series (1986-2014), the average annual inflow from gauged and ungauged catchments is approximately 269 Mm³ for Meki and 438 Mm³ for Katar (Goshime et al. 2020b).

In this study, analysis of time series discharge records results in a historical average annual discharge of 170 Mm³ (1980-2010) of the outflow from Lake Ziway to Lake Abijata via Bulbula River. In 2016, a weir was constructed at the outlet of Lake Ziway. The purpose of the weir was to stabilize the water level in the lake, and it seems to have decreased the outflow to Bulbula River (Jansen 2009). Lake Langano has several tributaries and one major outflow to Lake Abijata via Horakelo River. Lake Abijata is a terminal lake, has a small catchment itself and depends on inflows from Lake Ziway (via Bulbula River) and Lake Langano (via Horakelo River). Drawing from different sources, Figure 5 is an attempt at providing a steady-state water balance computation for the lake system.

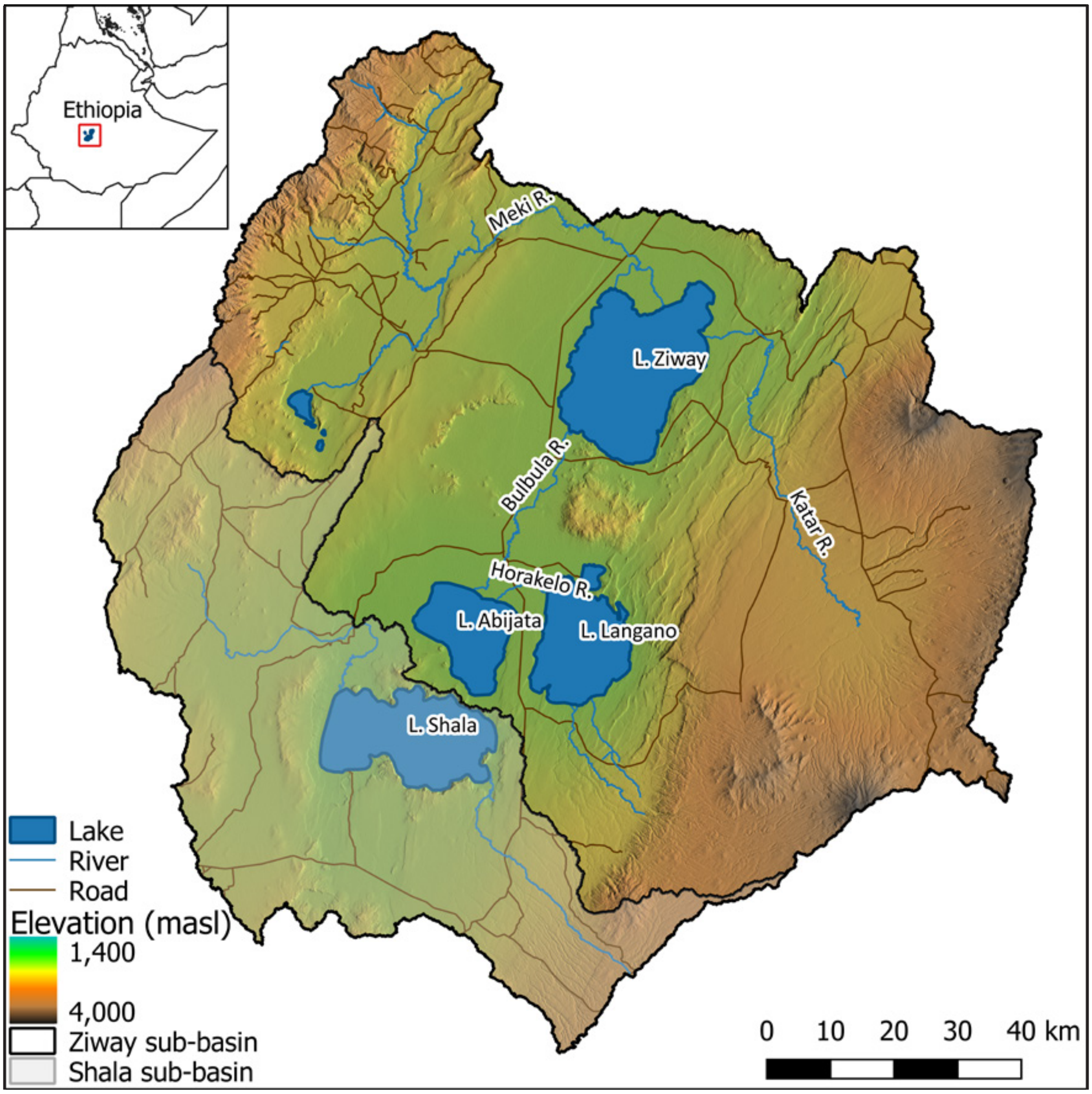


Figure 4. Overview map of the Ziway-Shala lake system situated in the Ethiopian Central Rift Valley.

Sources: The watershed delineation was provided by Acacia Water, The Netherlands, and the map was produced by hydrosolutions ltd., Switzerland.

Notes: L. - Lake; R. - River.

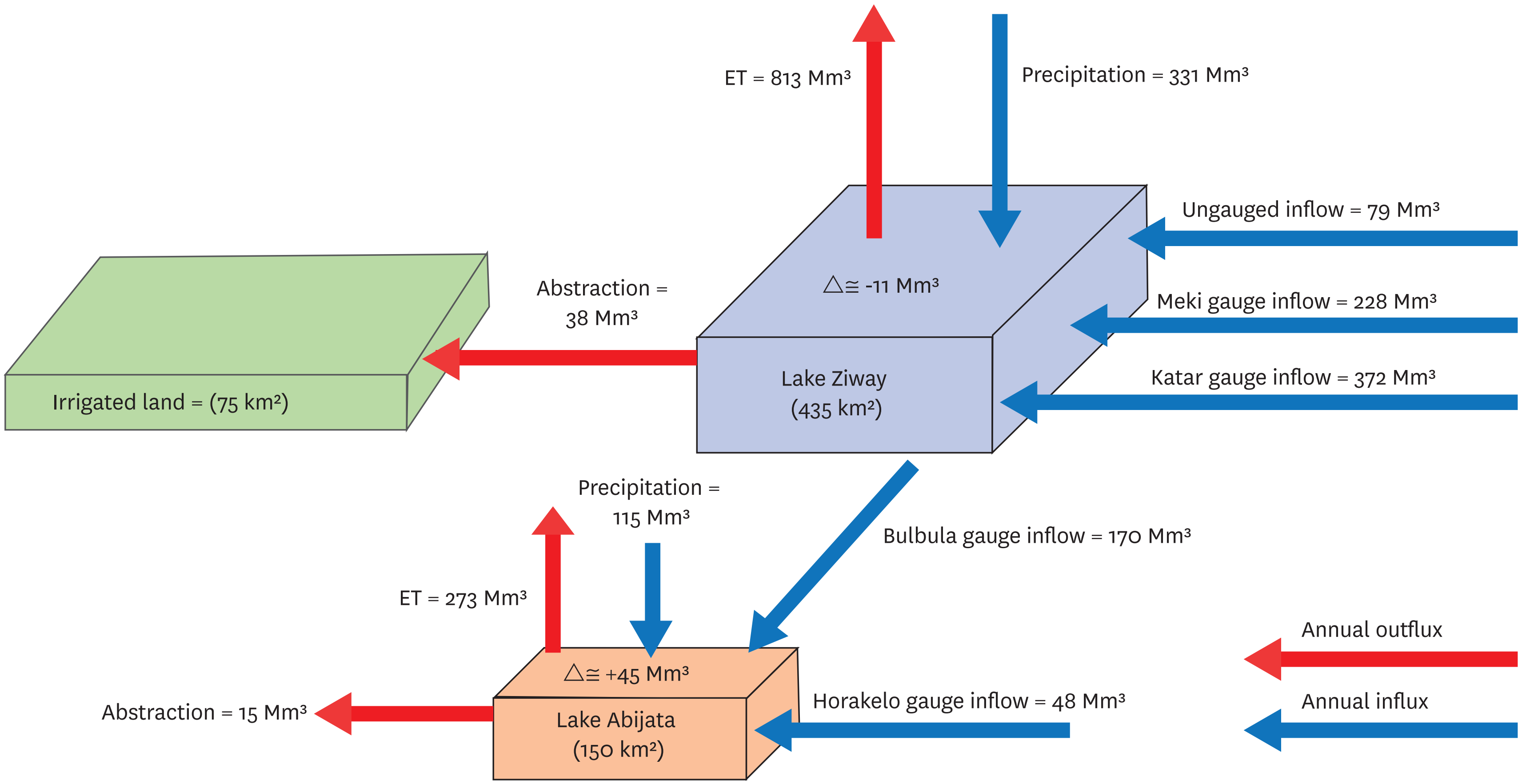


Figure 5. Preliminary long-term water balance of the Ziway-Abijata lake system.

Source: Created by hydrosolutions ltd., Switzerland.

Data period: 1986-2000 (except for abstraction data).

Data sources:

- Areas: Determined via remote sensing and area-elevation curve.
- Precipitation: Bias-corrected Climate Hazards Group InfraRed Precipitation (CHIRP) product (Goshime et al. 2019).
- Inflow: Historical data and rainfall-runoff simulation (Goshime et al. 2020a).
- Evapotranspiration (ET) over lake: Penman method using three stations (Ziway, Ogolcho and Arata) near the lake.
- Ungauged inflow: Area-ratio from simulated gauge.
- Abstraction: Water abstraction surveys (Goshime et al. 2020b).

Notes: For an equilibrium system, changes in lake storage are expected to be zero. Given the best available information, this could not be achieved in this preliminary long-term water balance for Lake Ziway and Lake Abijata. We, therefore, conclude that there must be uncertainties in the water balance components.

Socioeconomics

Rapid population growth, poverty and land tenure arrangements are key factors that could increase the demand for land and water resources in the Ethiopian Central Rift Valley (Garedew et al. 2009). The socioeconomic developments in Ziway-Shala sub-basin threaten the livelihoods of thousands of farmers and fishermen, who rely on these scarce natural resources (Elias et al. 2019). Moreover, it is widely recognized that the Lake Ziway ecosystem, well-known for its natural beauty, biodiversity and birdlife, is at risk. The former Ministry of Water Resources (MoWR), therefore, developed a Master Plan for sustainable development and poverty reduction in 2009 (Halcrow 2009). Besides governmental institutions, numerous development organizations, supported by the international community, are providing support to improve water resources planning and management in the sub-basin.

According to the Rift Valley Lake Development Master Plan, issued by MoWR, population is expected to increase at a rate between 2.8% and 3.4% by 2020 (Halcrow 2009). As a result, more and more people are claiming agricultural land for food production (Goshime et al. 2020b). In the uplands of the sub-basin, rain-fed agriculture is dominant and typical crops cultivated include maize, wheat and teff (Meijeren and Van Der Poel 2019). Irrigated agriculture is practiced mainly around the shores of Lake Ziway as well as around Meki, Katar and Bulbula rivers (Acacia Water and MetaMeta 2015). Water-intensive crops such as tomato, onion and cabbage are cultivated in these areas and sold to the markets in Addis Ababa (Meijeren and Van Der Poel 2019). The expansion of irrigated agriculture can be observed in satellite images. In 2000, an area less than 50 km² was irrigated around Lake Ziway (Acacia Water and MetaMeta 2015). From remote sensing images, it was identified that this area has increased now to approximately 75 km². However, based on a water abstraction survey conducted by Goshime et al. (2020b), Lake Ziway is supplying water to 20 km² of irrigated land excluding the irrigated area around Bulbula River at the outflow of the lake. This large deviation between irrigated areas reported by different analyses indicates the need for further validation of the methods used for monitoring.

Along the western shore of the lake, numerous smallholder farmers use portable diesel pumps to irrigate their fields (Figure 6). These smallholders account for

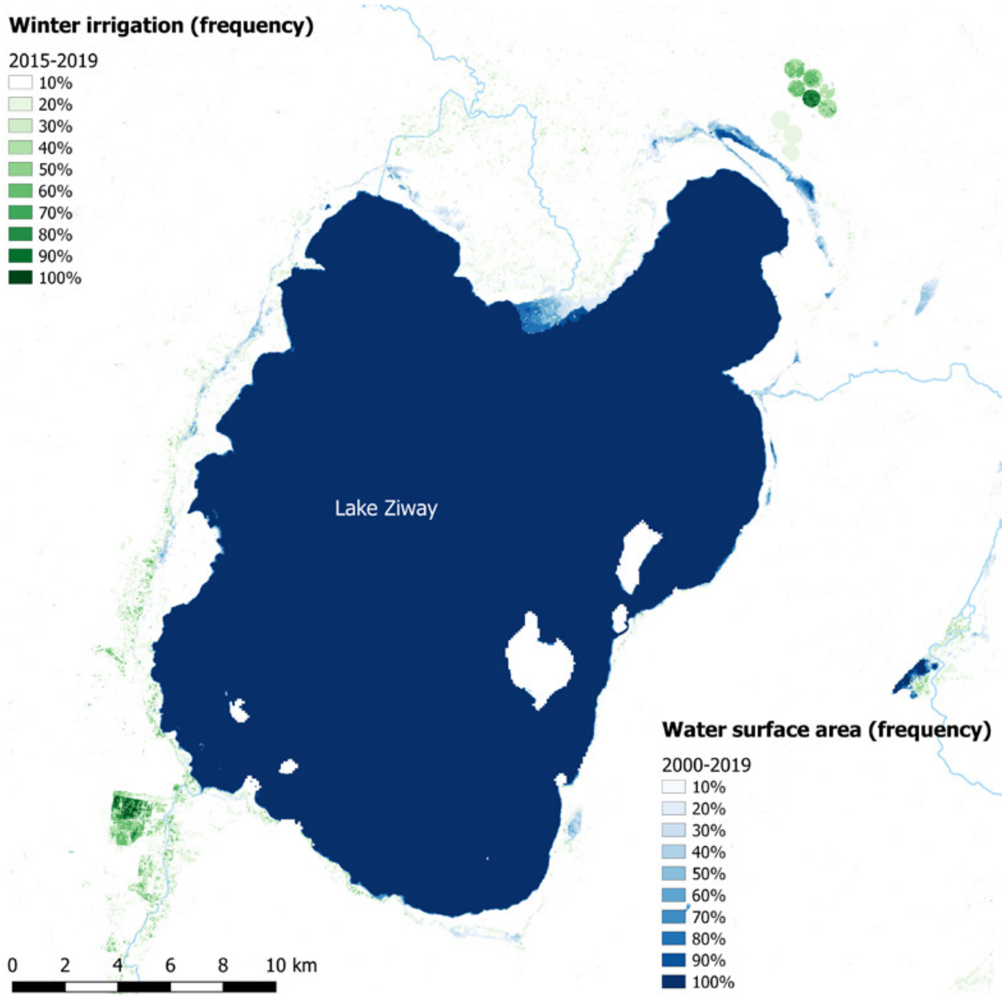


Figure 6. Dry season irrigated agriculture is practiced around the shores of Lake Ziway.

Source: hydrosolutions ltd., Switzerland.

more than 50% of irrigation water use around Lake Ziway, according to water abstraction surveys conducted by Goshime et al. (2020b). Moreover, several commercial farms use surface water for large-scale horticultural and floricultural production (Seyoum et al. 2015). It is very difficult to monitor water abstracted for irrigation around the shores of Lake Ziway, and local authorities seem to lack the capacity to establish sustainable abstraction scenarios, limits and policies. Water from the saline, terminal Lake Abijata cannot be used for irrigation. However, a soda ash plant situated on the lakeshore abstracts water for salt production. Current soda ash production amounts to 25,000 tons with an annual water abstraction rate of 150 m³ per ton, according to the Rift Valley Master Plan (Halcrow 2009).

Hydrological monitoring

Sound water allocation planning requires long-term, complete and reliable hydrological data. Previous studies have struggled with incomplete time series in Ziway-Shala sub-basin due to the unavailability of recent hydrological data, and have therefore relied on historical time series (Acacia Water and MetaMeta 2015; Goshime et al. 2019, 2020a).

Despite the lack of hydrological data from the ground, it is evident that the Ziway-Shala lake system is out of the equilibrium. Figure 7, derived from a series of satellite images, shows how the terminal Lake Abijata is shrinking dramatically. Between 2000 and 2019, its water surface area decreased from 164 km² to 55 km² (at its dry season minimum in 2019).

Even though the water surface area of Lake Ziway did not significantly decrease over the same period from 2000 to 2019, there are still concerns related to its water balance. The outlet of the lake has been regulated by a weir since June 2016. Therefore, flow to Bulbula River and Lake Abijata is expected to decrease, but this could not

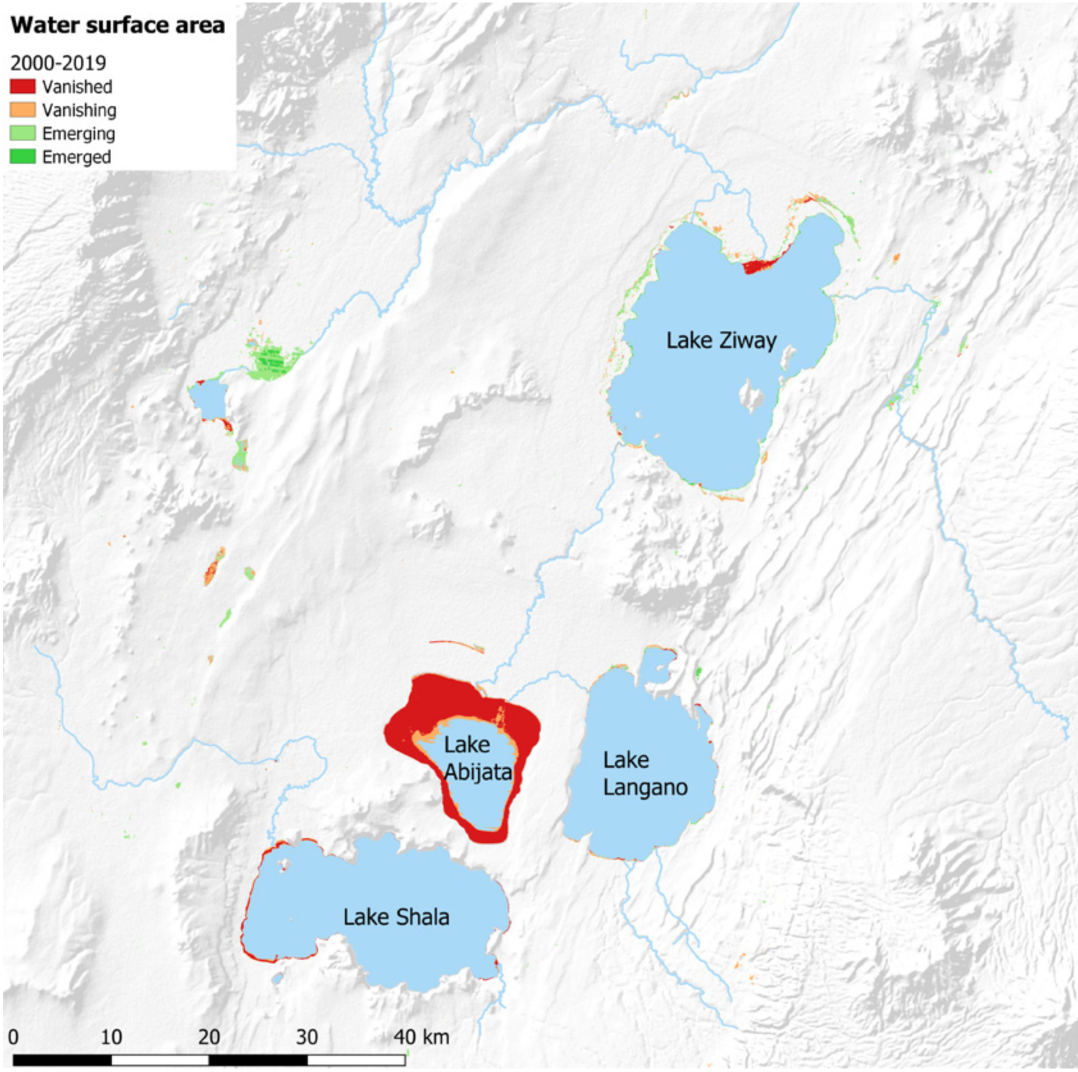


Figure 7. Water surface areas of the lakes showing a drastic decrease in the area of Lake Abijata.

Source: hydrosolutions ltd.

Notes: Red indicates the water surface area during the period 2000-2004, but this had decreased during the period 2015-2019, as shown in light blue. Green indicates wetlands that have emerged during recent years since the start of the study period in 2000.

be determined due to the lack of outflow data for recent years. According to farmers along Bulbula River, there has been a decrease in flow in the last few years and the river even ceased to flow during the dry season. This had not occurred before construction of the weir. Lake Ziway may eventually become a terminal lake due to its reduced outflow. This may cause an increase in salt concentration in the lake, and its water will then not be useable for irrigation (Jansen et al. 2007). Moreover, sediment accumulation potentially decreases the water volume of Lake Ziway (Aga et al. 2018).

The uncertainty of Lake Ziway's water balance is due to the paucity of available data. Based on available hydrological data, an annual water surplus of 11 Mm^3 was calculated (Figure 5). No long-term trend in water level and surface area of Lake Ziway can be detected. However, there have been lake level fluctuations over the past decades. Therefore, it can be concluded that the annual surplus of 11 Mm^3 reflects the order of magnitude of uncertainty in the input (and output) data.

Existing Data Collection Process

In 2016, the Rift Valley Lakes Basin Authority (RVLBA) took over the responsibility for hydrological monitoring in the Central Rift Valley from the Ministry of Water, Irrigation and Energy (MoWIE). The structure of RVLBA has changed since then. In September 2018, the Basin Development Authority (BDA) was established at national level. Therefore, RVLBA was renamed as Rift Valley Lakes Basin Development Office (RVLBDO). The main office of the RVLBDO is situated in Hawassa and the branch office, responsible for the Ziway-Shala sub-basin, is in Ziway.

The current data collection process for manually operated gauging stations in the Ziway-Shala sub-basin is presented in Figure 8. Each gauging station has an observer who is employed on a part-time basis by the RVLBDO. It is the observer's responsibility to measure the water level at the staff gauge twice daily (at 6 am and 6 pm) and note the values in a recording book. The hydrological technician is responsible for conducting velocity measurements at the gauging stations three times a year. The observers are supervised by the hydrological technician, who sits in the RVLBDO in Hawassa. The hydrological technician is also responsible for collecting the recording books and paying salaries (accompanied by an accountant) to observers at around 20 gauging stations in the Central Rift Valley. The transaction is supposed to happen every 3 months. The recording books are then taken to the main office of the RVLBDO in Hawassa, where the data should be digitized. However, no data are currently digitized due to the lack of data encoders at the RVLBDO, among other factors.

Although not currently practiced, after digitization at RVLBDO in Hawassa, the data collected should be transferred to the Hydrology and Water Quality Directorate at MoWIE, where all hydrological data (including rating curves) are centrally managed for Ethiopia. The process is different for most automated gauging stations, which are usually installed by MoWIE. Data from automated measurement sites are directly collected by staff from MoWIE and, in many cases, such information is not available at the basin level offices.

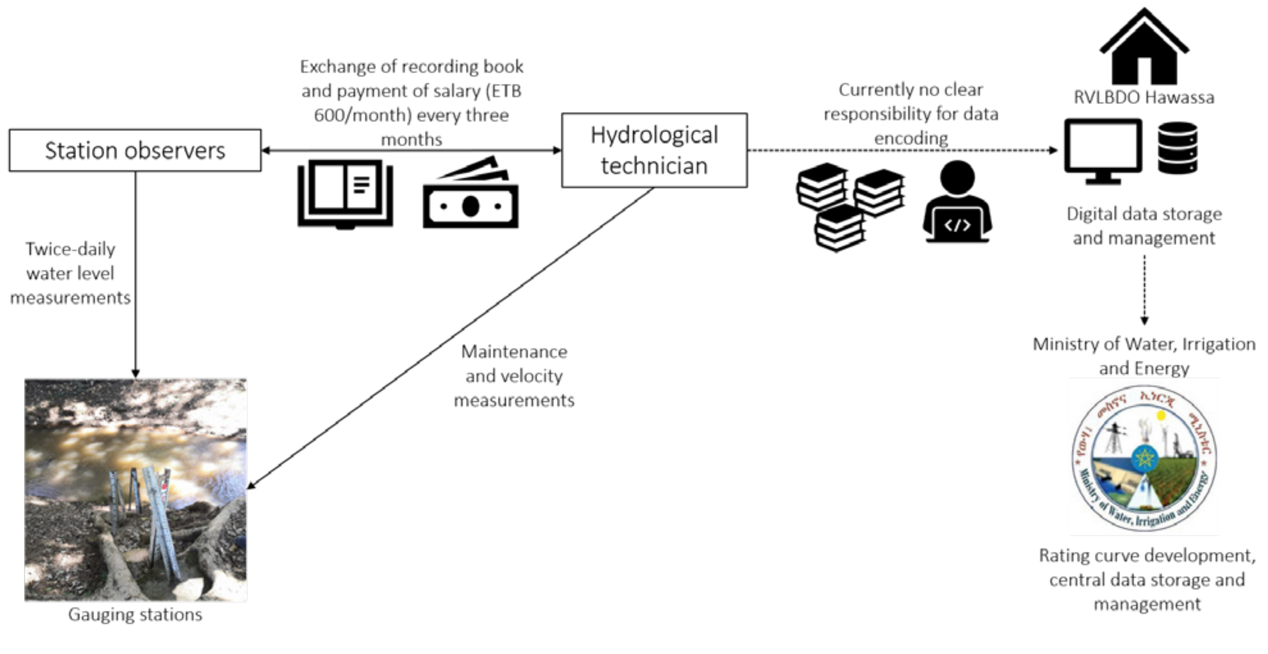


Figure 8. Current data collection process for manually operated gauging stations in the Ziway-Shala sub-basin.
Inset photo: Tabea Donauer.

Methods

For the purpose of this paper, information obtained from stakeholder interviews was combined with data collected during field visits to several gauging stations. Furthermore, existing hydrological data in Ziway-Shala sub-basin were rearranged to obtain a systematic overview of the available data.

- Stakeholder interviews: Stakeholders from the different institutions involved in data collection and management were interviewed to identify critical steps in these processes. No discharge data are available in digital form after 2010 (see Annex 1, Figure A1). Therefore, it became necessary to identify the Strengths, Weaknesses, Opportunities and Threats (SWOT) in the current process, and how to overcome existing problems. The following people were interviewed:
    - Hydrologist who previously worked for MoWIE
    - Several experts at the main office of the RVLBDO in Hawassa
    - Three experts at the RVLBDO branch office in Ziway
    - Hydrological technician
    - Ten observers who were responsible for conducting manual measurements at the gauging stations. Interviews with the observers were conducted following the protocol detailed in Annex 2.
- Field visits: Thirteen (10 river gauging and 3 lake level) measurement sites were visited to get a systematic overview of the network of existing stations. The protocol followed to assess the different stations is detailed in Annex 3. This includes the following:
    - General information about the station, such as its location, year of establishment and responsible observer
    - Assessment of the physical condition of the stations
    - Characterization of the river and channel properties at the gauging site
    - Assessment of the recording books handed in by observers (e.g., neatness of writing, possible suspicious patterns in the measurement, completeness, etc.)
- Collection and analysis of existing data: RVLBDO provided the locations of their existing gauging stations. This information was compared with our findings from the field. Historical water level and discharge data were obtained from MoWIE.

Hydrological Monitoring: Gaps

Problem Analysis

The core problem for water resources planning in Ziway-Shala sub-basin is the poor quality and large intermittency of hydrological data. Time series obtained from MoWIE are incomplete. Considering the large number of blanks in the recordings (see Annex 1, Figure A1), data continuity decreases after 2005. After 2010, no discharge data are available for the key stations at Meki, Katar and Bulbula rivers. This indicates that the problem with data quality started before the monitoring was handed over to the RVLBDO. The decline in data quality is due to the reduced attention given by the Hydrology and Water Quality Directorate at MoWIE, in general, and to monitoring programs, in particular. Recent institutional restructuring and transfer of some responsibilities to the RVLBDO have created additional confusion. A former hydrologist of MoWIE confirmed that these difficulties exist in most regions of Ethiopia, and that the quality of hydrological data collected is generally poor, particularly for recent periods.

Insufficient budget allocation and attention to hydrological monitoring by the government has caused severe deficiencies in the process described in Figure 8. These problems are presented in Figure 9 along the dimensions of data acquisition, exchange, analysis and management, and explained in detail in the following sections.

Gauging Stations

It was identified that the locations of the gauging stations provided by RVLBDO differed from the situation on the ground. Some stations were found several kilometers from where they were indicated in the official information. This is because the basin office uses geographic coordinates obtained from topographic maps, and they have not measured the station coordinates in the field. Moreover, some of the stations, such as the station at Lake Shala indicated in the official information (see Figure 10), are not operating anymore. Also, there are other newly installed stations such as Desta Abijata (station number 5) at Bulbula River.

It was identified that no measurements have been taken from Lake Abijata for several years. Due to the decline in the water surface area of the lake, the station had to be continuously shifted inwards and the datum had to be changed. According to the observer, who is still employed to measure the level of water in Lake Abijata, the basin office gave up on monitoring in this lake 2 years ago. An overview of the stations visited, a quick assessment of their physical condition and some recommendations are summarized in Table 1. The detailed field reports and assessments of the gauging stations can be found in Annexes 4 and 5.

One of the main problems encountered at most of the stations is damaged staff gauges. During the flood season every year, the staff boards installed by the RVLBDO are affected. It was identified that the markers and numbers had faded in some gauges, indicating that the staff boards are of poor quality. At certain stations, staff boards have been repeatedly stolen or vandalized. This is often immediately reported by observers to the RVLBDO. However, the common procedure is that observers are advised to use sticks with centimeter marks to measure the water level, but it is often unclear to what datum their measurements refer (Figure 11). Moreover, most of the stations visited do not have stable cross-sections. Bank erosion and sedimentation have changed the channel bed profiles over the years. The observer at Chiufa Arata (station number 3) has even reported 1 m of sediment deposition on the channel bed. To allow for more accurate measurements at the gauging sites, the following measures are recommended:

- High-quality staff gauges that can withstand the high flow should be installed.
- Frequent maintenance of the stations is needed, and damaged staff gauges must be replaced soon after the flood season.
- Frequent updating of the rating curves is required.

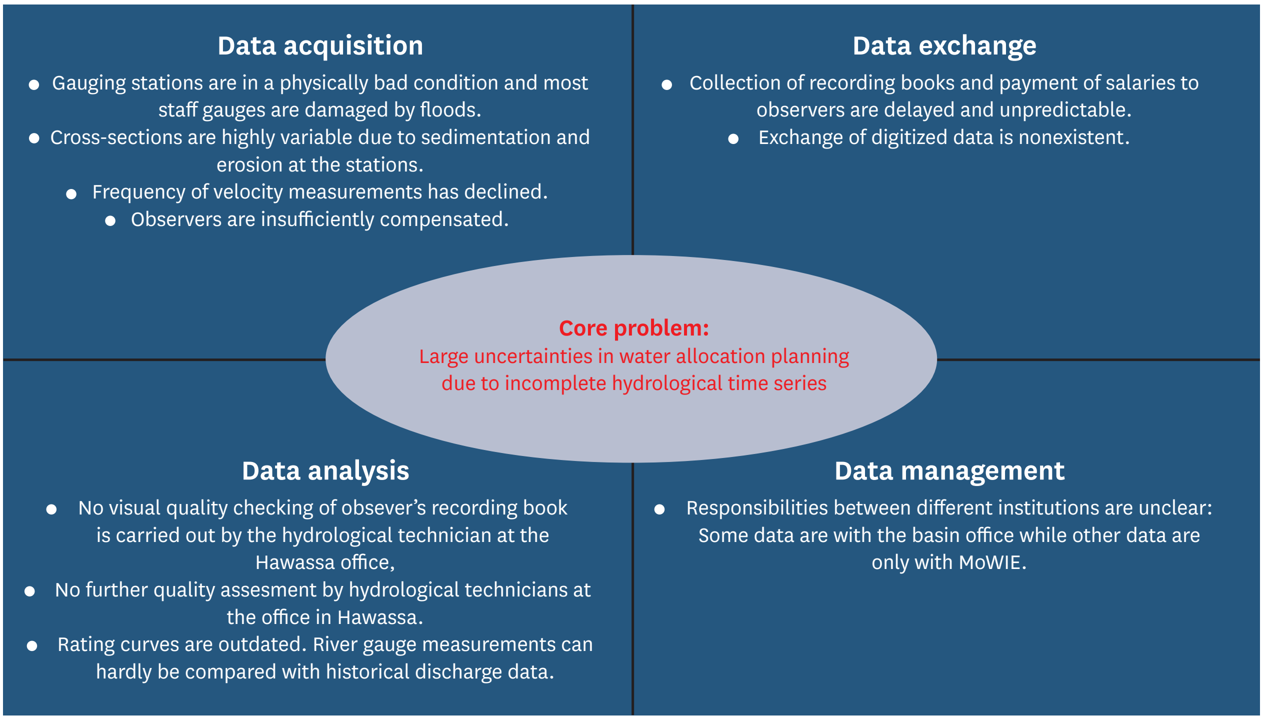
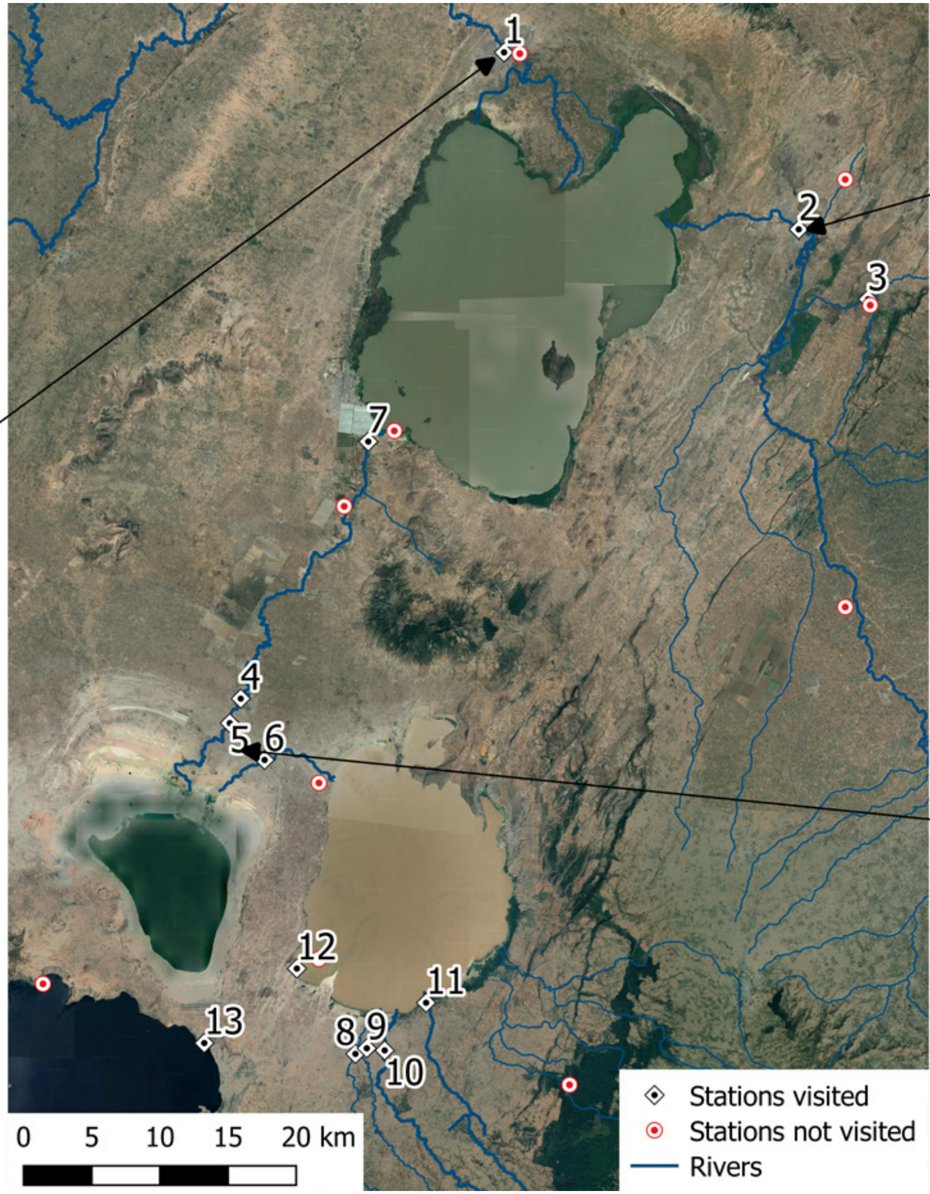


Figure 9. Stakeholder interviews revealed a variety of reasons for the poor monitoring in Ziway-Shala sub-basin.

Meki at Meki Town (1): Staff gauge is rusty and the reading has almost disappeared. There are waste and sediment deposits on the riverbanks. Open defecation near the station interferes with data recording.



Katar at Ogolcho (2): The staff gauge is in an acceptable condition. Due to the wide cross-section, velocity measurements are difficult during high flow conditions.

Bulbula at Desta Abijata (5): The lowest staff gauge is damaged by the flood. The observer uses a stick to measure the water level. No reference benchmark is visible.

Figure 10. Overview of the gauging stations visited and their locations provided by RVLBDO.

Photos: Tabea Donauer.

Table 1. An overview of stations visited, their physical condition and recommendations.

Station number	Station name	River/Lake	UTM Coordinates		Station condition and recommendations
			X (Easting)	Y (Northing)	
1	Meki at Meki village	Meki	480487	900899	Dangerous and dirty location, with thugs and gang members hanging around the station. Equipment installed here is prone to vandalism, the site is used to deposit waste and open defecation takes place. Major maintenance is needed for the staff gauges and the rating curve should be updated frequently.
2	Katar at Abura	Katar	502103	887930	Dangerous location due to recent political instabilities. The observer gets threatened by a younger man who is eager to take over the job from the current observer. Minor maintenance of staff gauges needed. Very difficult to conduct velocity measurements during high flow. Due to the stable cross-section, less frequent updating of the rating curve is required.
3	Chiufa at Arata	Arata	507177	882811	Major maintenance is needed for the staff gauges and the rating curve should be updated frequently.
4	Bulbula Town	Bulbula	461178	853556	Currently, no staff gauge is installed. A new location should be selected at a straight river reach instead of the current location where the river takes a bend.
5	Desta Abijata	Bulbula	460374	851761	Major maintenance is needed for the staff gauges and the rating curve should be developed. No velocity measurements have been carried out here yet.
6	Horakelo near Langano	Horakelo	462929	849064	Minor maintenance of staff gauges, stable cross-section and less frequent updating of the rating curve is required.
7	Lake Ziway Regulation	Bulbula	470530	872387	Gauging is not the main purpose of the site, but there is a concrete weir to regulate water level in the lake. The site is safe and the cross-section is stable, so data should be collected from here. There is an operating rule for design discharge, but it would be good to check its validity with velocity measurements.
8	Huluka Bridge	Huluka	469589	827534	No official gauging site by MoWIE, but a buried angle iron suggests that some monitoring had been conducted previously (possibly for research purposes). Flow is very irregular, and it is not a good location for discharge measurements.
9	Lepis Bridge	Lepis	470421	827942	Major maintenance is needed for the staff gauges and the rating curve should be updated frequently.
10	Gedameso near Langano	Gedameso	471736	827788	Major maintenance is needed for the staff gauges and the rating curve should be updated frequently.
11	Gurracha Bridge	Boku	474772	831276	Major maintenance is needed for the staff gauges and the rating curve should be updated frequently.
12	Lake level Langano	Lake Langano	465294	833785	Good location, safe and minor maintenance of staff gauges is required.
13	Lake level Shala	Lake Shala	458501	828325	Currently, no staff gauge is installed. It is not clear whether the observer has any reference point for measurement.

Notes: Station coordinates (UTM Zone 37N, datum = WGS 84) were measured on the field. This differs from the coordinates provided by the basin office, which were derived from topographic maps.

(a)

(b)

Figure 11. Observers taking measurements at gauging stations. (a) the observer at Desta Abijata (Station number 5) must climb a ladder to measure the water level with a stick, and (b) the observer at Meki at Meki Village (Station number 1) deals with a dirty and dangerous measurement location.

Photos: Tabea Donauer.

Observers

From the interviews conducted, it was identified that most of the observers are motivated and well-trained to carry out their duties. Some observers and their families have been responsible for the monitoring of a station for 30 years. They have all received at least one training, and most have participated in several trainings in different cities over the years. From the 13 stations visited, only two observers were women while all the other gauge readers were men.

Several problems were identified while conducting the interviews. All the observers stated that their salary was unsatisfactory and gave a variety of reasons. Some observers, who had been employed for many years, claimed that their actual salary (in USD) used to be higher in the past and salary increases did not keep pace with inflation. Others argued that their work was risky, especially during the high-flow season, or they had to walk long distances to the gauging station. One observer mentioned the problem of being employed on a part-time basis, which means that insurance and pension benefits are not provided. This observer suggested keeping the salary constant, but recognizing them as full-time staff.

It became clear that observers were promised equipment such as rain boots or umbrellas during ministry trainings. They were also promised tools to clear the site of vegetation and debris. However, none of the observers had ever received any of the items promised. Furthermore, observers are not satisfied with the supervision and assistance they receive from the basin office, which is explained further in the section *Hydrological Technicians*. The following is recommended based on the interviews conducted and field observations:

- Assess whether the observer's salary is indeed too low for the work carried out. Salary should be frequently adjusted according to the exchange rate (USD versus ETB), as this commonly affects the cost of living in Ethiopia.

- Observers can be given salary increases or an upgrade to full-time status by getting them involved in additional tasks such as carrying out minor maintenance work.

- Some observers can be involved in other activities related to the measurements they take, such as data encoding at the basin office. This will help to increase awareness of the value of the data collected by the observer.

- Observers should be provided with the equipment necessary to carry out their work, such as rain boots and umbrellas. Having such items will facilitate taking measurements during the wet season. At the same time, equipment branded with the official logo of MoWIE could help increase awareness of the observer's position within their community.

- Maintaining a guest book at the station could help to track visits to the gauging sites. Hydrological technicians should include the following details in the book: dates when they visited the sites, and whether they conducted maintenance work (according to the World Meteorological Organization [WMO] guidelines on streamflow gauge maintenance [see section *Basin Development Office*]), velocity measurements or similar tasks. Other visitors to the stations, including nongovernmental organizations and researchers, should also include these details in the guest book. Recording such information will help to receive feedback on data collection and stations, as well as to identify the interest in the gauging stations.

- A protocol could be prepared and shared with researchers, so that they submit their data to the RVLBDO after their research is published.

Hydrological Technicians

Hydrological technicians are based at the basin office in Hawassa and their responsibilities include meeting the observers every 3 months, collecting their recording books and paying them salaries. Interviews conducted highlighted that all observers are unsatisfied with the timing of salary payments, and complain about delayed and unpredictable salary payments. At the time of the visits, observers consistently stated that payments were currently delayed by 4 months.

Less than half of the observers stated that the hydrological technicians visit the gauging stations to collect the recording books. Only three out of 10 observers stated they received feedback on their recordings. One observer even stated that, "nobody would notice if we did not visit the gauging site and just provided some false values." This observer strongly recommended hydrological technicians to inspect the data collected for suspicious records during the visits. Figure 12 shows that some of the errors made by the observers are simple to avoid through supervision. The following measures are recommended to improve the quality of supervision:

- Delayed and irregular salary payments are a big concern of the observers. The RVLBDO has already identified this challenge and plans to set up a system with monthly salary transfers to observers' bank accounts. All observers are requested to open a bank account.

- The hydrological technician should also maintain a book, with one page for each visit to the station. The book specifies the protocol to follow and each page must be signed by the station observer. The protocol should include the visit to the gauging site, remarks on maintenance required, cross-checking the observer's measurement for the current date (conducting the measurement together), giving feedback on the observer's recordings and highlighting any irregularities in the measurements, if any. The protocols should be collected in the basin office, allowing the responsible director at the RVLBDO to control the work of the hydrological technicians.

- There used to be a hydrological technician in the branch office of the RVLBDO in Ziway, which is closer to the stations than the main office in Hawassa. This position was abandoned, which meant that the technician from the main office in Hawassa was responsible even for minor station maintenance. There should be a person in Ziway who is responsible for providing support to the technician from the main office with timely station maintenance and gauge reader supervision. This person should be provided with the necessary training, enabling them to give observers feedback on hydrological data quality.

Responsibilities of the hydrological technician also include maintenance of the gauging stations and conducting velocity measurements. However, rating curves to convert water level measurements to discharge data are constructed by hydrologists at MoWIE, because only they have access to the data management software. At the moment, they use very old, analogue current meters for velocity measurements. According to the ministry protocol, velocity must be measured three times a year – during low, mid and high flow – at each station. It was identified that this has not happened in Ziway-Shala sub-basin since 2016, and the only recent velocity measurements were taken during low flow conditions. A cableway system (poles on both banks carrying cables), which must be installed on both sides on the riverbank to measure velocity during high flow conditions, have frequently been stolen, because local people found other personal uses for these cables.

A further problem is that, currently, there is no practical education for hydrological technicians. There used to be a two-year program at Arba Minch University (previously the Arba Minch Water Technology Institute), which is not being conducted at the moment. Technicians that were hired recently are graduates of water-related engineering programs. Graduates of these programs are often not motivated to visit the field and do not have the required training to develop rating curves. The following are suggested to overcome problems related to rating curve development:

- A more modern, digital current meter is required to facilitate velocity measurements. The purchase of four modern current meters is proposed. This will provide access to spare meters and help to involve the Ziway branch office in velocity measurement. Existing or future projects can support the RVLBDO in purchasing these current meters, which cost about USD 3,000 each and is affordable for many projects.

- Alternative technologies should be considered to allow for measurements during mid and high flow conditions. Remote-controlled Acoustic Doppler Current Profiler (ADCP) boats could be

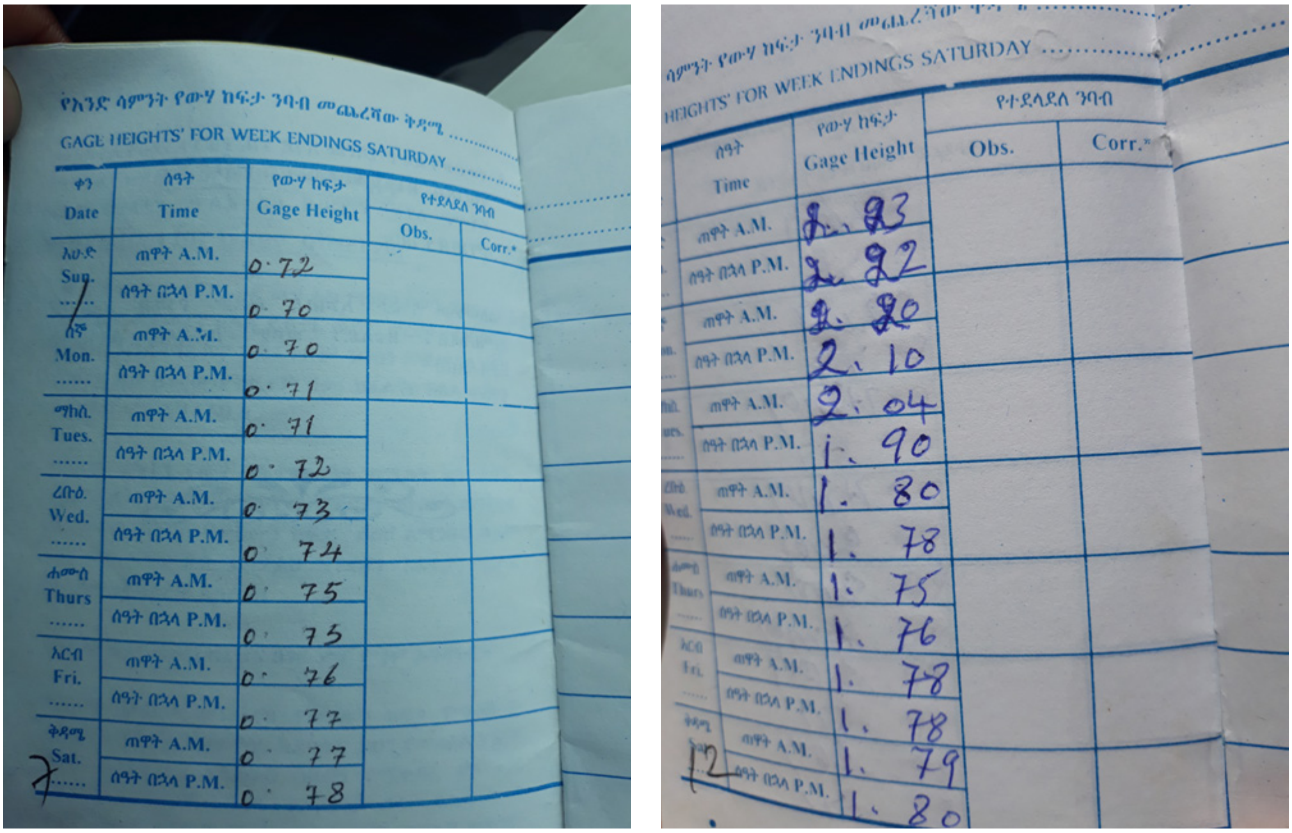


Figure 12. Examples of the recording books maintained by observers at gauging stations.

Photo: Tabea Donauer.

Notes: We found suspicious patterns (most often, increasing water level) and unclear handwriting in some books. These examples show the importance of cross-checking and feedback from the hydrological technician of the RVLBDO main office in Hawassa.

an accurate but very expensive option. A simpler option would be to use software such as Discharge[1], which allows for non-intrusive, optical flow measurement. The tracer-dilution method could also be an option to determine flow in wide cross-sections with varying riverbed profile. However, these methods need to be tested first for the stations in Ziway-Shala sub-basin.

- Junior hydrological technicians should be trained and motivated to visit the field. This can be done either through workshops organized by external organizations or ideally through the reintroduction of the former practical education course at Arba Minch University. There is also a need to revise per diems to adequately cover accommodation and food expenses of technicians during field visits.

- Install a cableway system for velocity measurement during mid and high flow conditions, and ensure its security by working closely with local officials and communities. This system would be quite expensive and should, therefore, be implemented only for key stations.

Basin Development Office

It was identified from the field visits that the responsible basin institutions currently lack the financial and human resources required to maintain the streamflow gauges as recommended by WMO guidelines (Box 1).

Box 1. WMO Guidelines for Streamflow Gauge Maintenance.

(a) Check the bank stability, as necessary.
(b) Check the level and condition of gauge boards, as necessary.
(c) Check and service the flow-measuring devices (cableways, etc.), as necessary.
(d) Check and repair control structures, as necessary.
(e) Regularly survey cross-sections and take photographs of major station changes after events or with vegetation or land-use changes.
(f) Record, in note form, all of the above activities and their results.
(g) Inspect the area around or upstream of the site, and record any significant land-use or other changes in relation to hydrological characteristics, such as ice.

Source: WMO 2008.

[1] Discharge (https://discharge.ch/) – A platform for professional surface flow measurements comprising DischargeApp (a smartphone app) and DischargeWeb.

Printed copies of the recording books for the period 2016–2019 are stored in the main basin office in Hawassa. There are expert hydrologists capable of interpreting and managing the data in these books. However, nobody is responsible for data encoding and, therefore, there is no digital version available. It is not clear whether this is due to a lack of resources for data encoding or unclear responsibilities and accountabilities, especially since there are 20 people employed at the basin branch office in Ziway. The following recommendations are put forward for the basin development office:

- Digitization of the recording books does not take much time. Each book contains 180 data points, which should be typed into a Microsoft Excel spreadsheet by the hydrological technician in the main basin office soon after collecting the recording books.
- Students can be employed to carry out digitization of the books collected over the last few years. Some station observers can also be involved in this work.
- Setting up of a data management system should be considered besides digitization of existing measurements. It should provide the basin office with simple access to hydrological data in the Central Rift Valley. A platform for the Awash Basin[2], including hydrological data as well as information about water use and demand of big irrigation farms, is currently under development and could potentially be extended to the Central Rift Valley.
- Rating curves need to be upgraded and established at the basin office in Hawassa, by building the capacity of the hydrologists and providing them with access to old rating curves, which are archived at MoWIE.

Availability of Hydrological Data

Streamflow and lake level data are crucial inputs for hydrological model simulation and to quantify the long-term water balance of the basin. However, the density of streamflow gauge stations in the Ziway-Shala sub-basin is low. The station network was established four or five decades ago. Therefore, it is not optimized to capture current water abstraction in the basin.

MoWIE provided the streamflow, lake level and outflow records for the doctor of philosophy (PhD) study by Goshime et al. (2019, 2020a, 2020b). The dataset covers the period 1984–2014 at a daily time scale. Staff of RVLBDO stated that printed copies of water level data were already available. MoWIE are not sharing data for recent years because water level records are neither digitized nor converted to streamflow. Table 2 shows a summary of the river discharge and water level data of the study area. The records from many of the stations have substantial data gaps.

Table 2. Hydrometric stations in the study area - location and data availability.

S.no	Station name	Location		Catchment	Observation		Data type
		Latitude	Longitude	Area (km^2)	Available period	Number of years with missing data	
1	Meki at Meki village	8.15	38.83	2,433	1984-2010	8	Q
2	Rinzaf at Butajira	8.12	38.37	49	1984-2005	9	Q
3	Katar at Abura	8.07	39.05	3,350	1984-2014	5	Q
4	Sagure at Fite	7.78	39.05	1,975	1984-2007	4	Q
5	Chiufa at Arata	7.98	39.07	216	1985-2007	6	Q
6	L. Timala at Segure	7.68	39.15	184.4	1984-2007	5	Q
7	Kekersitu at Adami Tulu	7.85	38.72	7,488	1984-2015	6	Q
8	Horakelo near Langano	7.67	38.70	2,006	1984-2007	6	Q
9	Gedemso near Langano	7.47	38.67	1,179	1995-2007	4	Q
8	Lake Ziway at Ziway	7.90	38.75	7,736	1984-2015	1	WL
9	Lake Abijata at Aroressa	7.55	38.70	10,744	1984-2013	2	WL
10	Lake Langano at Hotel	7.53	38.52	2,006	1984-2013	2	WL
11	Lake Shala	7.49	38.62	-	1984-2012	3	WL

Note: Q represents streamflow and WL represents water level data.

[2] The public interface of the platform for the Awash Basin – https://dmmangrove.hkvservices.nl

Hydrological Monitoring: Opportunities

In the previous sections, critical steps and gaps in the current data collection process were identified and recommendations for improvement were provided. The aim of these recommendations is to increase the quality of the measurements and ensure the measured data are accessible by the basin office. Besides supporting the existing institutions, further opportunities for non-traditional hydrological monitoring should be considered. Non-traditional monitoring can provide complementary datasets to data that can be obtained from the gauging network operated by the RVLBDO.

Many Ethiopian universities offer graduate programs in water-related subjects. This can be considered as an opportunity; options for students to generate and systematically archive hydrological data at the RVLBDO should be investigated. International organizations operating in the Ziway-Shala sub-basin are willing to invest and can help to improve the monitoring situation as well. Both research and development projects can generate hydrological data to fill gaps. However, it is essential to coordinate such actions well, establish clear protocols guiding the handing over of data to the RVLBDO and make the generated data accessible to the authorities at the basin level.

Remote sensing data offers huge opportunities to improve hydrological monitoring in Ziway-Shala sub-basin, and also allows the filling of some historical data gaps. As an example, continuous time series of lake water level can be derived from satellite radar altimetry. A product for Lake Ziway is available through the Database for Hydrological Time Series of Inland Waters (DAHITI)[3] (Schwatke et al. 2015). It covers the period starting from 2008 up to the present day (Figure 13).

The decrease in the water surface area of Lake Abijata is evident when considering optical satellite images (see Figure 7). By combining the change in lake surface area with topography/bathymetry data, the change in lake volume can be estimated.

Furthermore, there are remotely sensed products available to estimate precipitation. They can be improved through bias correction algorithms and used for rainfall-runoff simulation (Goshime et al. 2019). There is a strong need to generate and use gridded precipitation products for the sub-basin, integrating data from multiple satellite products, and data from rain gauges which are operated by the government and research organizations.

Evapotranspiration maps can be developed from remote sensing imagery (Figure 14) and calibrated with ground-based data (Allen et al. 2007). Such maps can be combined with data on irrigation water application to produce irrigation efficiency maps. Evapotranspiration maps can also demonstrate how land-use changes, such as deforestation or soil degradation, affect evapotranspiration and, therefore, potentially the basin's water balance.

To estimate irrigation water demand, water abstraction surveys for the Lake Ziway area have been conducted in a previous study (Goshime et al. 2020b). These surveys can be further improved and extended to obtain water abstraction data for different seasons and years. At the same time, a scheme irrigation accounting system could be developed and introduced as, for example, successfully carried out in irrigation schemes in Central Asia (e.g., Innovative Technologies for Monitoring, Modeling and Managing Water [iMoMo][4]).

Gauge readers could be equipped with modern discharge measurement technologies such as the smartphone-based DischargeApp. As the app measures surface velocity at the same time as water level, a rating curve can be developed in a convenient manner over time. All the measured data are stored and analyzed first on the mobile phone. These data can then be synchronized via Wi-Fi or a Global System for Mobile Communications (GSM) network to a database for quality control and approval by supervisory personnel, e.g., a person such as the hydrological technician from the main basin office in Hawassa. From the online database, the data can be accessed via a user interface or exported to comma-separated values (CSV) files, and can then be used for further reporting, analysis and exchange.

The performance of this optical flow measurement technique has been tested under laboratory conditions as well as in natural streams in Switzerland (Carrel et al. 2019; Odermatt and Wild 2018). However, when introducing the DischargeApp as a complementary measurement method for stations in Ziway-Shala sub-basin, it needs to be validated against traditional velocity and water level measurements.

In comparison with other systems, one advantage of the Discharge platform is that a time-stamped image is taken and stored in the database for every measurement. Therefore, an authority that has commissioned gauge readers to use such a portable technology can easily obtain visual proof that the measurement was *actually* taken. This could reduce the occurrence of fraudulently reported data, among other things. This is particularly true since some observers stated that they can fraudulently report data without being detected, due to the lack of supervision and cross-checking of data collected.

[3] dahiti.dgfi.tum.de
[4] iMoMo Central Asia – http://wua.imomohub.kg/#

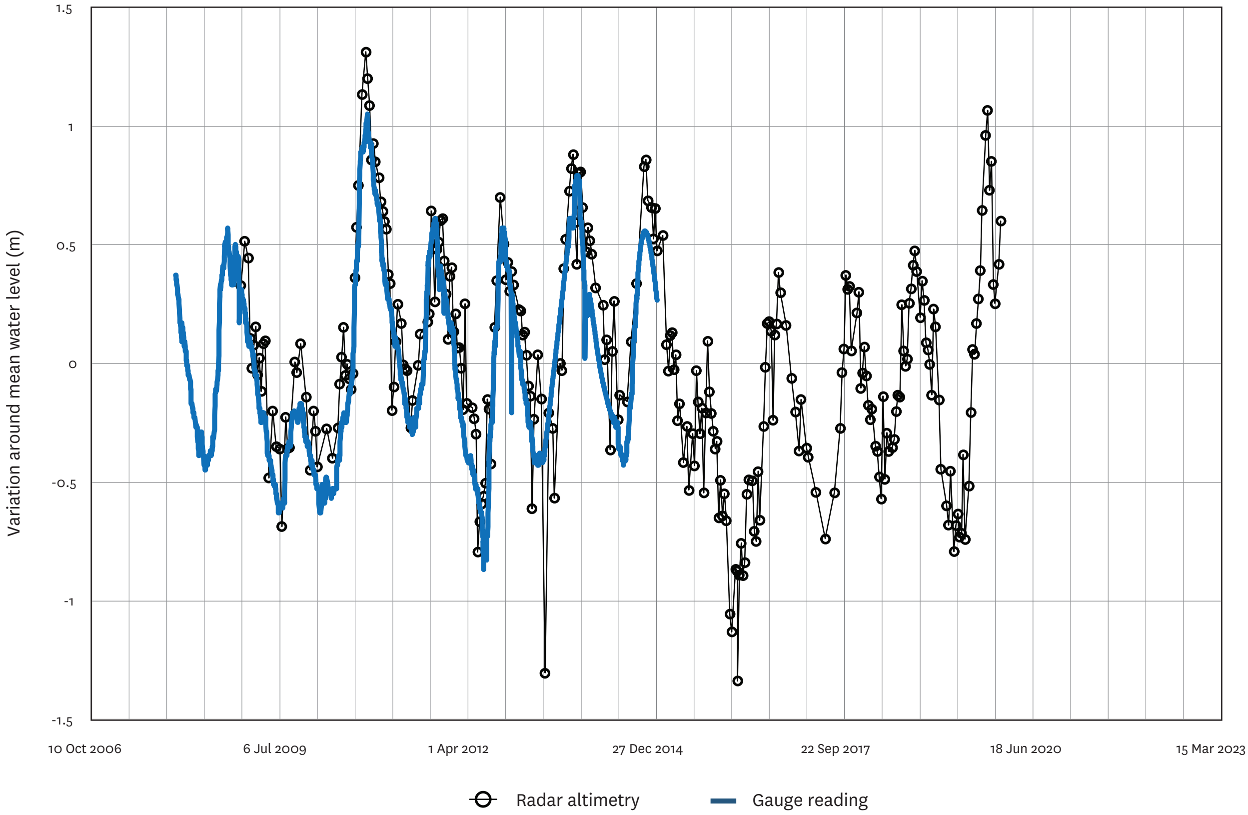


Figure 13. Lake level measurements from radar altimetry compared to gauge reading for Lake Ziway.

Source: Schwatke et al. 2015.

Notes: Historical data obtained from the gauging station at Lake Ziway validates the remote sensing product obtained online through DAHITI.

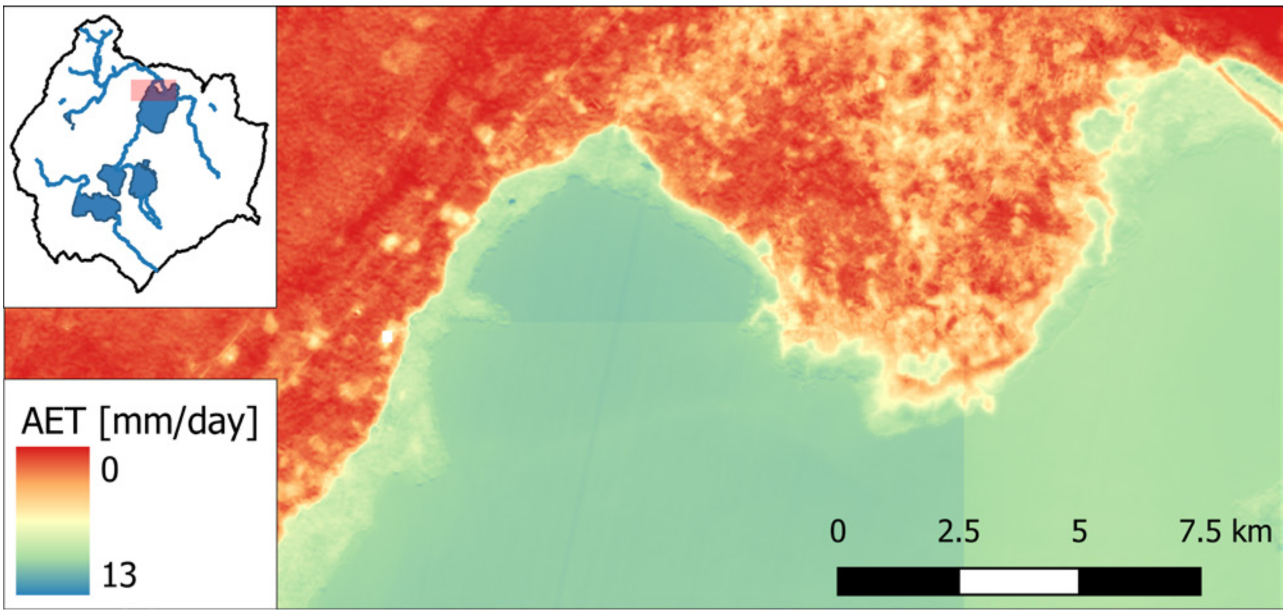


Figure 14. High-resolution map of actual evapotranspiration at the shore of Lake Ziway.

Notes: The Mapping EvapoTranspiration at high Resolution using Internalized Calibration (METRIC) algorithm (Allen et al. 2007) was used to estimate actual evapotranspiration from a Landsat image taken on January 16, 2019. The spatial resolution of 30 x 30 m allows for observing irrigation activity on a field scale. AET - Actual evapotranspiration.

Finally, water quality (e.g., salinity) can provide information about water quantity. Rising salt concentrations in Lake Ziway may indicate decreased lake outflow to Bulbula River (Jansen 2009). To measure water quality, a community-based monitoring program could be established. Such programs have provided reliable measurements in previous projects (Walker et al. 2016). The International Water Management Institute (IWMI) is already testing the scope of embedding the 'citizen science' approach into the regular monitoring of selected water quality parameters in key locations in Meki catchment and Lake Ziway. Citizen science refers to the participation of the general public (i.e., non-scientists, citizens or community members that volunteer) in the generation of new scientific knowledge, together with professional scientists (Buytaert et al. 2014). Lessons can be drawn from this scoping study to expand the citizen science approach to the entire sub-basin. Common concerns with the approach include data quality and control, incentives for citizen scientists and sustainability of the monitoring.

Discussion and Conclusion

This paper provides an overview of the current situation with regards to hydrological monitoring in the Ziway-Shala sub-basin in the Central Rift Valley of Ethiopia, including details of existing river and lake gauging stations in the sub-basin. Historical streamflow and lake level data can be accessed from MoWIE, but most time series end in the years 2005-2010 (see Table 2). Since 2016, the RVLBDO has been responsible for hydrological monitoring. However, they are unable to provide an electronic version of any time series. The lack of data is a key challenge for all water allocation planning, including irrigation, in the sub-basin.

Field visits and interviews conducted highlighted that even though there is no electronic version of recent data, there is an existing network of gauging stations in Ziway-Shala with motivated observers responsible for taking water level measurements. Recording books are collected at the basin office at Ziway, where young and well-educated experts are employed.

Damaged gauging stations, outdated rating curves for most stations and the lack of capacity to digitize the data at the basin office are the main problems in the existing data collection process. By supporting the basin office to overcome these challenges, it is possible to obtain some streamflow and lake level time series for the period between 2016 and 2019. If rating curves are developed, past water level data can be converted to discharge time series using the new rating curves. For some stations, where the river morphology did not change significantly (e.g., Katar), the possibility of using the old rating curve in the absence of recent velocity measurements may be explored.

Besides supporting the existing institutions, a range of opportunities to complement traditional monitoring were discussed. These opportunities include data collection through remote sensing and community-based (e.g., using the citizen science approach) measurements, and require further assessment of feasibility and usefulness to decrease the huge uncertainty in the water balance of the lake system.

Using the citizen science approach has twin benefits: (i) citizens will be empowered through enhanced understanding of their environment, and (ii) researchers and practitioners obtain useful data. Since 2014, IWMI in collaboration with Newcastle University has been testing this approach, mainly together with farmers, for hydrological monitoring in six small watersheds in Ethiopia. This involved monitoring of rainfall, streamflow, springs and shallow groundwater levels. Their findings indicate that the quality of data collected using citizen science is acceptable (Walker et al. 2016), and can be used to understand the water resources potential of previously ungauged catchment behavior (Ferede et al. 2020).

However, the use of citizen science for formal hydrological monitoring complying with RVLBDO guidelines requires careful study to understand regulatory and institutional aspects as well as measurement quality constraints. If such considerations are not taken into account from the beginning, the contribution of citizen scientists might not be appreciated as the lack of proper training and supervision may lead to data that are ultimately unusable. Furthermore, stringent quality assurance and control measures need to be put in place to ensure consistent data are collected over time. Lastly, long-term motivational aspects require special attention as interest and willingness of citizen scientists to continue taking measurements beyond a well-specified date might wane over time. Haile et al. (2019) and Walker et al. (2019) provide more information on setting up citizen science programs.

Research and development projects can generate additional hydrological data to fill gaps. However, if external organizations are involved in the collection of hydrological data, this needs to be well coordinated with the RVLBDO. Uncoordinated action of different projects, as well as political and institutional instability are factors threatening the current monitoring system. Table 3 presents the Strengths, Weaknesses, Opportunities and Threats (SWOT) as identified in the current study.

Table 3. Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of hydrological monitoring in Ziway-Shala sub-basin.

Internal factors	
Strengths (+)	Weaknesses (-)
• Existing network of gauging stations • Committed observers; some have been taking measurements for 30 years • Young, motivated and well-educated people at the sub-basin main and branch offices • Printed copies of the data are available for the period since 2016 at the sub-basin main office in Hawassa • Most stations are easily accessible by car	• Most stations are in a physically bad condition (lack of station maintenance) • No updated rating curves are available for all the stations • Observers are insufficiently supervised and assisted by the hydrological technicians • Nobody is responsible for digitization of data at the RVLBDO • Lack of timely revision of salaries with reference to inflation
External factors	
Opportunities (+)	Threats (-)
• Several organizations working on projects in the basin are willing to invest and support existing institutions in hydrological monitoring • Use of remote sensing data to complement ground-based time series and fill historical data gaps • Collaborate with the network of 10 universities to involve students in filling data and information gaps • Extend water abstraction surveys • Collect data through community-based measurement campaigns, such as for water quality monitoring	• Institutional instability; a lot of restructuring and redistributing of responsibilities in recent years • Stations are vandalized and observers are harassed because community members do not understand the purpose of the hydrological monitoring • Uncoordinated action of different projects in the sub-basin causes confusion for the authorities and local population • Absence of institutions that train hydrological technicians

Notes: Strengths and weaknesses of the current hydrological monitoring processes led by the RVLBDO, as well as further opportunities to improve data collection and external factors threatening the system were identified.

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Annex 1. Data Availability.

Streamflow measurements started in 1969 for Meki, 1970 for Katar and 1980 for Bulbula. Figure A1 shows blanks in the discharge data obtained for the Meki, Katar and Bulbula rivers. No data were accessible in digital form after 2010. However, the time series are very incomplete after 2005.

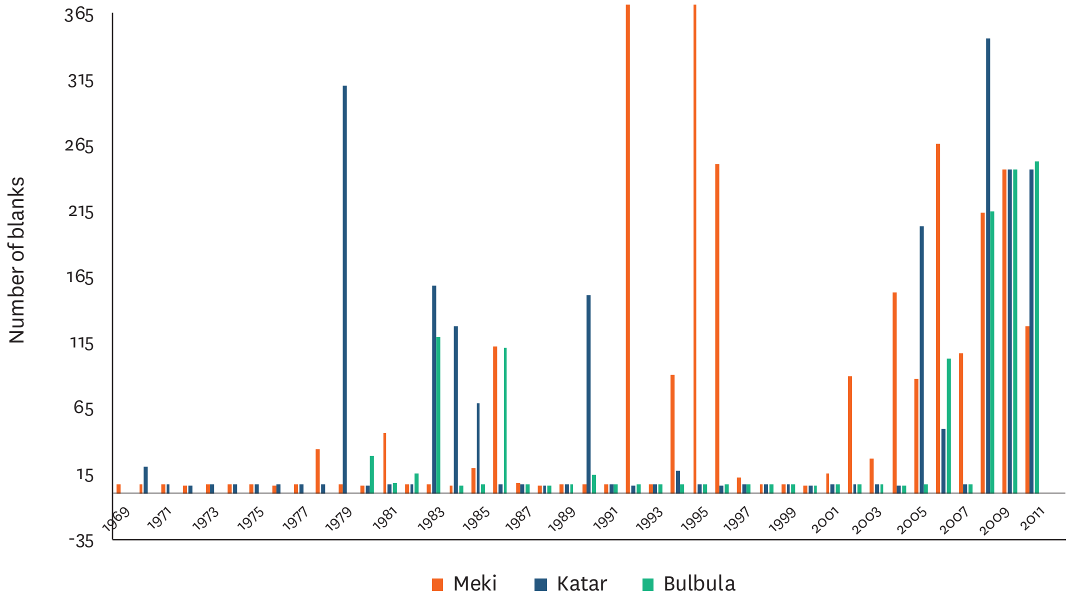

Figure A1. Blanks in historical streamflow measurement data at key gauging stations.

Notes: There are years with few recordings for Meki, Katar and Bulbula stations before 2000, but blanks in the data seem to accumulate systematically after 2005. Streamflow data for these stations were last available in 2010.

Annex 2. Observer Interview Protocol.

Basic profiles

Name of the observer: ______________________________ Sex: ________ Age: ________

Level of education: _________________________ Year of enrollment: __________________

Training and capacity building

1. What trainings did the observer receive?
2. At what frequency?
3. When was the last training?
4. Who provided the training?

Supervision work

5. What is done by the supervisor when visiting the site?
6. Is any feedback provided on the data quality?
7. What does the observer suggest to improve the quality of supervision?

Solving problems

8. Does the observer inform the basin authorities if something went wrong at the gauging site?
9. What line of communication is used?
10. Do they respond quickly?
11. Are there any factors that interfered with data collection in the past?

Data quality

12. How does the observer assess site safety or convenience to take measurements?
13. How well are peak flows captured by the specified observation times (twice a day at 6:00 am and 6:00 pm)?
14. At what time of the year do peak flows usually occur?
15. Has any flooding occurred in the past? How often and when?
16. How does the observer capture the flood?
17. What is the longest period during which recording was interrupted?
18. Why was it interrupted?
19. When was the last time velocity was measured?
20. Has the gauging site changed? If yes, when was it changed?
21. For what reason?

Satisfaction

22. When was the last date the observer received their salary?
23. Rate the observer's satisfaction with the salary, in terms of
    - timeliness, and
    - amount.
24. Did the observer receive any incentives in addition to the salary in the past?

Annex 3. Station Assessment Protocol.

Date and time: _____ /_____ /_______ /______:_______

Name of the observer and telephone number: ____
____

Station name and ID: ___________________ Year of establishment: ____________ River name: ________________

Recorder type: __________________ Height of staff gauge: ________________

X coordinate: _______________ Y coordinate : ______________ Elevation: ___________

Description of access route including distance and condition of the road: _____________________________________
____

Length of straight reach upstream and downstream of the site _____________________________________

Channel width at the site: __________

Months of maximum and minimum flow: ______________________________

Stage (water level) reading during the field visit: ______________________

	Y/N	Remarks
Physical condition of the staff gauge		
1. Is the staff gauge free from obstructions that hinder flow such as weeds, debris, tree barks and rock outcrops?		
2. Is the staff gauge mounted on a structure, such as a bridge or weir, for support?		
3. Is the staff gauge high enough to capture low and high floods?		
4. Is the staff gauge bended or tilted from the normal vertical axis?		
5. Is the staff gauge clearly visible and easy to read (are there centimeter marks)?		
6. Is the site subject to sediment deposition and/or scouring problems?		
7. Is the zero reading on the staff gauge aligned exactly at the bed of the channel?		
8. Did the zero reading on the staff gauge change over time due to sediment deposition and/or scouring problems? If so, how?		
9. Is the staff gauge likely to be affected by floods, turbulence and wave action?		
10. Does the site have a deep pool which will reduce the velocity?		
11. Are there any cattle crossing the site which will affect flow reading?		
Property of the river and channel		
12. Does the river have a straight reach?		
13. Is the cross-section uniform?		
14. Are the riverbanks stable laterally and vertically both upstream and downstream?		
15. Are the banks high enough to contain the high flood?		
16. Does low flow not concentrate and take place in a wide and shallow stretch?		
17. Does the river cease to flow? If yes, what is the duration of no-flow?		
18. Is the flow normal to the cross-section of the river?		
19. Are there any flood marks on the riverbank, nearby grass or tree?		

(Continued)

	Y/N	Remarks
Observer and his recording book		
20. Does the observer collect and record data frequently and consistently up to recent dates?		
21. Does the observer have a standard recording book which is used to include the information in a correct, clear and neat manner?		
22. Is there any noticeable suspicious pattern in the data recording sheet?		
23. Are there any footprints of the observer at the gauging site (indicating frequent and recent monitoring)?		
24. How long does it take the observer to arrive at the station from their house?		

Annex 4. Field Report Summary: Lake Level Stations.

Lake Ziway

The gauging station at Lake Ziway (station number 10) could not be visited during this field trip. From personal communication, it was identified that the automated measurement equipment at the lake is no longer functional. Historical data can be obtained, but there is a shift in the datum, when the location of the station was shifted. It is not clear when this shift happened. Supposedly, there is still a staff gauge installed.

Lake Langano

The gauging station at Lake Langano (station number 12) is located within a 10 minute walk from Langano village, which can be reached by a 3 km drive over a dirt road from the main road. Most of the reading on the gauge at the station is damaged and the observer uses a stick to take measurements (Figure A4.1). In the dry season, the lake recedes and the water level cannot always be captured. However, consistent data from this station is expected, since the observer's family has taken measurements with dedication since the gauge was installed around 1990. New staff gauges must be installed at this site, including additional staff gauges to capture low water levels.

Figure A4.1. Lake level station at Lake Langano.

Photos: Tabea Donauer.

Lake Abijata

The gauging station at Lake Abijata (station number 11) is now located hundreds of meters away from the lakeshore, due to decrease in the water surface area of the lake. The last measurements were taken at least 2 years ago, and prior to that, the gauging station has been continuously shifted according to the decrease in the water level. The observer still receives payment from the basin authority, although it is not possible to record any measurements.

Lake Shala

The gauging station at Lake Shala (station number 13) is located 6 km west of the main road. There is a dirt road leading to a village and from there, it is another 3 km walk or rough four-wheel drive down to the lake. There is no staff gauge installed. The location does not seem ideal, as there is nobody living nearby. Current data from Lake Shala cannot be trusted, as there are no signs of frequent reading, the observer could not be identified and there is no reference point to measure (Figure A4.2).

Figure A4.2. A local villager explains how the observer measures the water level in Lake Shala.
Photo: Tabea Donauer.

Annex 5. Field Report Summary: River Gauging Stations.

Meki at Meki Village

The gauging station Meki at Meki Village (station number 1) at the Meki River is located around 50 m downstream of the bridge at the main road in Meki Town. It used to be situated right under the bridge where the riverbed is stable, but was moved downstream some years ago.

The measuring site is strategic and important to quantify the inflow from Meki River to Lake Ziway. However, the location of the bridge in Meki Town is unsafe, prone to vandalism and there is a lack of awareness of the purpose of taking measurements. Many people dump their waste on the bridge (Figure A5.1) and open defecation takes place. An automated measurement station, which was previously installed, has been vandalized and is not in operation anymore. According to the surveys, it became apparent that any expensive equipment installed nearby would be stolen or damaged by gangsters within a few days. Parts of the staff gauge have also been vandalized and stolen in the past. It needs to be replaced, and frequent maintenance and cleaning are necessary in the future. The basin authority should look for solutions to prevent vandalism together with the population.

Figure A5.1. The bridge in Meki Town serves as a waste dump. The site is unsafe, dirty and prone to vandalism.
Photo: Tabea Donauer.

The cross-section where the gauge is currently installed has changed due to sediment deposits. The reason for this might be that Meki used to be a perennial river but now ceases to flow in the dry season. During low flow, sedimentation occurs, which has decreased the width of the channel. Frequent updating of the rating curve is required.

Katar at Abura

The gauging station Abura (station number 2) at the Katar River is located 50 m upstream of the bridge in Ogolcho. A 25-30 km drive on a dirt road from Meki Town is required to reach this bridge. The staff gauge is mounted on a solid structure built for the automated station (Figure A5.2). It is in good condition and can withstand floods. Data were collected from the automated station in 2019, so it is supposedly still in operation. The location is strategic, since the majority of Katar catchment (with an area of 3,740 km^2) contributes to the discharge here.

Figure A5.2. The majority of Katar catchment contributes to the discharge measured at the gauging station in Ogolcho.
Photos: Tabea Donauer.

The site does not feel safe. There have been problems with local people harassing and threatening the observer of the manual station. Furthermore, the staff gauge needs to be cleaned and maintained after flood events. For the automated station, data need to be downloaded after the rainy season to prevent the loss of valuable high flow data. The basin authority should, therefore, frequently visit the site to ensure continuous operation of both the manual and automated measurement.

The site has not been changed for a long time and the cross-section seems stable. Velocity measurements at this wide cross-section are challenging, especially during high flow conditions. As a first step, it is recommended to use the old rating curve to get an estimate of the discharge based on water level data which were collected in the last few years. In a second step, a new rating curve should be developed. This will require considerable time and effort due to the remote location of the gauging station.

Chiufa at Arata

The gauging station Chiufa Arata (station number 3) is located at the bridge crossing the Arata River. The bridge can be found at the end of Arata village after driving 40 km east on the dirt road from Meki Town.

The location is safe and protected by vegetation, which was planted by the observer. The gauge has been operated by the same family for 30 years. The river has a deep pool and a wide cross-section with low flow velocity at the measuring site. The water level might be insensitive to a change in discharge. This can be observed in the recording book. The water level sometimes remains constant for several days. Due to the wide cross-section, velocity measurements are difficult during high flow conditions. Floods frequently damage the staff gauge and the zero reading has severely changed over time due to sedimentation. The staff gauges need maintenance and the rating curve should be updated.

Bulbula at Bulbula Town bridge

The gauging station Bulbula Town Bridge (station number 4) at the Bulbula River is located on the main road through Bulbula Town at the bridge. The path to the river is steep, slippery and there is a lot of waste. The riverbanks at the location are stable and the cross-section close to Bulbula Town Bridge is suitable for discharge measurement. It is a key location, since the discharge here corresponds approximately to the inflow to Lake Abijata (all the big irrigation schemes are located upstream). The gauging site is close to the main road, allowing frequent visits and velocity measurements by the basin office. However, the place is busy with children and people from the nearby marketplace. It is prone to vandalism; the staff gauge was stolen 6 months ago. Currently, the observer uses a stick to measure from a benchmark. A new staff gauge must be installed, and the station must be maintained and cleaned frequently. Now, the observer measures close to a tree, after which the river bends. The new staff gauge should ideally be installed in a straight reach of the river.

Figure A5.3. The observer uses a stick to measure the water level at Desta Abijata gauging station.

Photos: Tabea Donauer.
Notes: The staff gauge was damaged by the flood. The staff gauge was very low quality and the observer could predict that it would not withstand the high flow.

Horakelo near Langano

The gauging station Horakelo Main Bridge (station number 6) at the Horakelo River is easily accessible from the bridge at the main road, which is 5 km south of Bulbula Town. The location is safe and there are no problems with vandalism, according to the observer, who lives nearby and has been responsible for the gauge since its establishment in 1982. The banks are stable and the velocity distribution at the cross-section is uniform. It is an adequate measuring site, and only minor maintenance of the staff gauge and updating of the rating curve are needed.

Langano Tributaries

Four gauging sites (station numbers 8 to 11) at tributary rivers to Lake Langano were visited: Huluka, Lepis, Gadameso and Boku stations. Except for the station at Huluka River, the stations are official and currently operated by the RVLBDO. All the stations need maintenance and frequent updating of the rating curves. However, they seem to be rarely visited due to their location far off the main road.

Bulbula at Desta Abijata

The gauging station Desta Abijata (station number 5) at the Bulbula River is safely located inside the private property of the observer, where there is an irrigated plot. It is located around 2 km off the main road and access is not very easy.

The cross-section of the river is suitable for discharge measurement. The site is relatively new and no velocity measurements have been conducted up to now. A rating curve for the site should be developed as soon as possible. The low-quality staff gauge, which was installed by the basin office, was damaged by the flood and the observer uses a stick to measure the water level (Figure A5.3).

The observer does not use a benchmark but tries to be consistent with the measuring site. A higher-quality staff gauge needs to be installed and frequently maintained. There is the option to install an automated measuring station here, because the location is protected by a fence.

Bulbula at Lake Ziway Regulation

The gauging station Lake Ziway Regulation (station number 7) at the Bulbula River is installed on the weir which regulates the water level of the lake. The weir is located around 3 km off the main road. The location is safe and well protected through the weir guard. The cross-section is stable and suitable for measuring discharge. Water level measurements are available from 2016, but they must be digitized and converted to discharge. The gauge is frequently controlled by the branch office and the quality of data is expected to be high.

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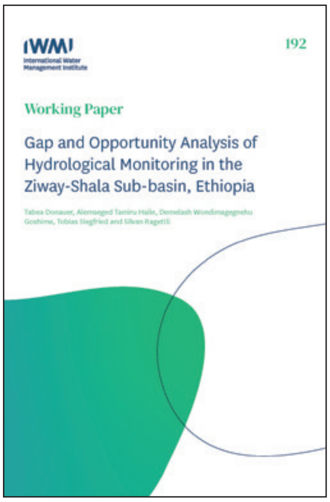

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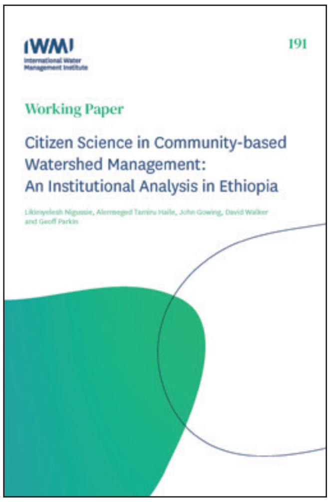

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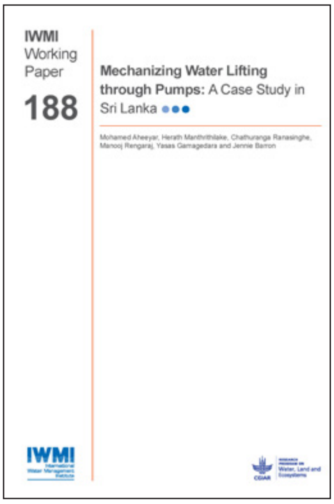

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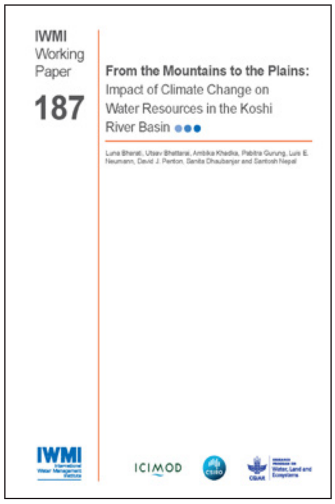

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