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Working Paper

Data Quality Deterioration in the Lake Tana Sub-basin, Ethiopia: Scoping Study to Provide Streamflow and Water Withdrawal Data

Meron Teferi Taye, Alemseged Tamiru Haile, Addisalem Genet, Yaregal Geremew, Sitot Wassie, Bewuketu Abebe and Bahiru Alemayehu

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Contents

Acronyms and Abbreviations

ABDO	Abbay Basin Development Office
FLAIR	Future Leaders – African Independent Research
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
IWMI	International Water Management Institute
MoWIE	Ministry of Water, Irrigation and Energy
PET	Potential evapotranspiration
SDG	Sustainable Development Goal
USA	United States of America
WADA	Water And Development Alliance
WEAP	Water Evaluation and Planning
WMO	World Meteorological Organization

Summary

Effective water resources management is dependent on having information about the status and distribution of water resources. Having more accurate and comprehensive information on components of the water cycle enables the sustainable development of water resources at basin/regional levels. In Ethiopia, hydrological data monitoring dates back more than half a century at different locations throughout the country. However, in recent years, there has been a decline in the quality and density of measurements, because some gauging stations are not working properly, rating curves are not updated, or stations are abandoned. More importantly, streamflow data for recent years are not available to users due to the problem of converting water level data to discharge. As a result, proper hydrological assessment is lacking for most basins and made it difficult to understand recent variations in river flow caused by climatic and human factors. Lack of recent knowledge on water availability and use will have increasing implications for the country's goals of poverty alleviation, increasing agricultural productivity, flood and drought forecasting, and increasing energy production.

The Lake Tana sub-basin, source of the Blue Nile River, is one of the locations selected by the Ethiopian government as a growth corridor for development activities, due to its water and land resources. However, this sub-basin also experiences a lack of hydrological monitoring of a good quality and quantity, as evidenced by the recent deterioration of river flow data. Despite booming irrigation activities, information on water withdrawals for irrigation is not available. Water use and water demand by other sectors are not explicitly known. The capability to collect and manage data remains inadequate in the sub-basin due to the lack of adequate financial resources and capacity to maintain and strengthen monitoring networks.

This scoping study, conducted under the Future Leaders – African Independent Research (FLAIR) program, was initially planned to understand hydrological changes within the Lake Tana sub-basin. However, after experiencing data challenges, the program prioritized generating primary data and demonstrating possible solution pathways to fill data gaps. We follow a co-planning process with staff from the Abbay Basin Development Office (ABDO) and *woreda* (district) experts on data measurement procedures, priority gauging stations, development of rating curves, and surveying irrigation water withdrawal sites and water demand sectors. With this approach, this study was able to measure streamflow velocity and use the data to develop rating curves for three key flow gauging stations at Gilgel Abay, Gumara and Ribb, which cover more than 80% of the sub-basin. Water withdrawals for small-scale irrigation schemes were estimated through studies conducted in 15 locations covering five *woredas* that have a total irrigated area of more than 1,000 ha per *woreda*. Water demand estimates for urban and rural water supply (drinking and domestic use), livestock, agriculture, industry and hydropower were obtained from government databases of each *woreda* in the sub-basin. Given that data on water withdrawals/demand were not compiled previously and due to the lack of recent river flow data, this study contributed to reducing the data gaps to support planning and development processes. Furthermore, the data compiled can be used to improve water allocation modeling and planning by ABDO. ABDO is currently working on a water allocation model (Water Evaluation and Planning [WEAP]) using old data and incomplete information on water withdrawals.

This study also highlighted the need for a data alliance among stakeholders in the sub-basin. It demonstrated the possibility of conducting such activities with limited financial resources at selected highly relevant locations. We have observed that it is more about commitment, partnerships that benefit data providers and users, and a strong conviction on the value of such data by all stakeholders that can drive the improvement of water data collection for decision-making. Through different projects, the International Water Management Institute (IWMI) has shown the gaps in and opportunities for monitoring hydrological data in various basins. This approach can be upscaled to national level.

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Introduction

It is expected that water resources management is supported by water-related data to make reasonable and beneficial decisions. There is an increasing demand for water data due to climate variability and its implications (Dinku 2019), including making robust decisions under an uncertain climate with limited data and advanced methods (Borgomeo et al. 2018), creating new awareness that humans are drastically altering the environment (Josset et al. 2019), and the need to monitor the progress of global, regional and national initiatives that promote development (Aboelnga 2019; UNFCCC 2020). For instance, the world is working towards achieving the United Nations Sustainable Development Goals (SDGs). Data are important to track the SDG indicators on water, climate, agriculture, energy, and socioeconomic status. Enhancing capacity-building support to significantly increase the availability of high-quality, timely and reliable data is one of the SDG targets, e.g., Goal 17, Target 17.18 (UNSD n.d.). Therefore, agencies such as UN-Water are working to increase the availability of high-quality data for evidence-based policymaking, regulations, planning and investments at all levels (UN-Water 2021). Similarly, the World Meteorological Organization (WMO) recognized the value of water-related data and is making an effort to increase the availability of information on water resources to support the SDGs (WMO 2021). UNFCCC (2020) highlighted that, at the global level, countries are entering into adaptation planning and implementation processes following the Paris Agreement on climate change. These processes require data to plan, implement and monitor adaptation, and ensure they are scaled up based on evidence of their efficiency and effectiveness. Such global efforts indicate that water is a top adaptation priority in a changing climate and a factor that various sectors should consider in adapting to climate change (WMO 2021).

Providing science-based solutions to adaptive and sustainable management of water resources at country and basin levels require readily available data on both water supply and demand to understand the present status and predict the future. For instance, according to McCartney and Girma (2012), the lack of information on water resources in the Blue Nile Basin is a major challenge when analyzing the implications of different investment options for the basin. Taking account of the water-energy nexus approach in research studies, policy and planning is hindered by gaps in data on water availability and quality (Larsen et al. 2019). Moreover, except for the United States of America (USA), most countries do not freely distribute or share water data (Lakshmi et al. 2018). Together with partner institutions, the World Bank recently launched a portal[1] that works as a one-stop shop for water data.

Most research articles refer to the river basins of Ethiopia as data-scarce regions; a quick search on Google Scholar using the words ‘Ethiopia’, ‘data-scarce’, ‘water’, and ‘hydrology’ resulted in 1,770 research articles (search carried out on December 15, 2021). This will increase to more than 100,000 research articles when the search is carried out using the words ‘Ethiopia’, ‘data’, and ‘scarcity’. While this highlights the scarcity of not only data but also other resources in the country, the need for water-related data is increasing for multiple reasons. In Ethiopia, there are massive, planned investments in irrigation, (agro-) industries, and sustainable land management activities, which require information on water availability, withdrawals, and seasonal changes to support such investments. However, high-quality data relevant for these purposes are either not available or not accessible or available with inadequate spatial and temporal coverage. For instance, by the end of 2018, the Ethiopian Basin Development Authority was operating 490 river gauge stations, of which about 50 stations were telemetered (Nigussie et al. 2020). However, the lack of reliable daily streamflow data has been reported for key river basins, including Omo-Gibe (Degefu and Bewket 2017), Upper Blue Nile (Haile et al. 2017), and Meki and Katar catchments of the Central Rift Valley (Goshime et al. 2019). This has implications for planning, designing, forecasting, and any water management-related activities. Mosello et al. (2015) stated that water resources management in Ethiopia is hampered by a lack of knowledge of resource conditions, patterns of use and drivers of change, and a lack of capacity and skills within institutions to plan water allocation, assess impacts and trade-offs, and ensure ‘climate-smart’ planning. They also found poor or non-existent linkages between data, information, decision-making and planning processes.

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[1] https://wbwaterdata.org/dataset

Moreover, there are discrepancies in research findings on hydrological trends of river basins partly due to uncertain data. Taye et al. (2021) provided an example of the Lake Tana sub-basin where the historical trends on the flows of the major rivers in the sub-basin vary depending on the time used for the analysis and data quality challenges. For the Gilgel Abay River, a decreasing trend in dry season flow was reported by Rientjes et al. (2011) for the period 1982–2005, Taye and Willems (2012) for the period 1964–2005, and Gebrehiwot et al. (2014) for the period 1960–2004. However, Tigabu et al. (2020) reported no siginficant trend in dry season flow in the Gilgel Abay River during the period 1973–2009. For the Gumara River, Abebe et al. (2020) reported decreasing trends in both low flow and wet season flow for the period of 1973–2018. However, Tigabu et al. (2020) reported a significant increasing trend in dry and wet season flows in the Gumara River during the period 1960–2015. The discrepancies in trends in the Gilgel Abay River are due to the time used for analysis by the different studies. In the Gumara River, the discrepancies in trends are due to data quality issues. In the Gilgel Abay River, data quality issues were identified after 2006. Moreover, there are issues related to the methods used to assess the quality of the data obtained from government entities by different researchers, which may lead to contrasting conclusions. Taye et al. (2021) and Worqlul et al. (2018) suggested the need to check the data quality in the Gilgel Abay River and others in Lake Tana sub-basin, especially after 2006.

Data discrepancy can be observed in different sectors such as irrigation, water supply, industries, etc. Data on the actual irrigated area within Ethiopia varies among studies and in government documents (Kedir 2021). For instance, using 2019 as the base year, an irrigated area of 1.2 million hectares (Mha) is reported by MoWIE (2020) and 0.58 Mha by MoA (2020), while it is 0.6 Mha according to survey data from the Central Statistical Agency estimated by Kedir (2021). The implication of such discrepancies is that the country is challenged when producing development plans that consider the available water and land resources, and other relevant aspects. It is also difficult to estimate the contributions of the agriculture sector to the national economy without having accurate figures (Kedir 2021).

With rising population and economic growth in a changing climate, water withdrawals and/or water demand are continuously increasing. Data on water withdrawals is, however, difficult to obtain due to limited regular monitoring, poor data collection and a poor archiving system, and fragmented data in different government offices without standard procedures and an overlap of mandates among these offices. In recent years, repeated changes in the organizational structure of the basin development authority have exacerbated these problems. The recommendation by Mosello et al. (2015) is that Ethiopia needs an operational plan with clear institutional mandates that clarify relations, especially between the regions and river basin offices, detailing who will do what, when it will be done, and how much it will cost. The International Water Management Institute (IWMI) piloted a study in the Ziway-Shala Basin and highlighted the challenges in hydrological monitoring from these different aspects, and suggested non-traditional monitoring approaches such as citizen science (Donauer et al. 2020). Goshime et al. (2021) conducted a water abstraction survey to fill data gaps in the Water Evaluation and Planning (WEAP) model for the Central Rift Valley sub-basin. Haile et al. (2022) showed the deterioration of streamflow monitoring in Omo-Gibe Basin and suggested the need to investigate the institutional barriers that affected the homogeneity, completeness and timeliness of streamflow data.

The Lake Tana sub-basin is one of the locations selected by the Ethiopian government as a growth corridor through which to increase irrigation and industries. The Abbay Basin Development Office (ABDO) is based in this region and in charge of executing different water management responsibilities. Through the Ethiopian government proclamations in 2008 and 2018 that are related to the establishment of the Abbay Basin High Council and Authority (Regulation No. 151/2008) and the Basin Development Authority (Regulation No. 441/2018), respectively, ABDO received the mandate to collect, compile, analyze and disseminate information for proper planning, administration and steering of water resources in the Blue Nile Basin. ABDO is expected to ensure that projects, activities and interventions related to water resources in the basin are in line with the integrated water resources management process. To conduct the activities stated above, proper hydrological monitoring of both water resources and water withdrawals is required. ABDO collects data on water level, flow velocity, sediment and water quality at different monitoring frequencies. However, the declining quality of streamflow data and the lack of information on water withdrawals in recent years (Taye et al. 2021) calls for the need for better attention (Taye and Haile 2021) to monitoring to make proper water management decisions.

Through the Future Leaders – African Independent Research (FLAIR) Fellowship program, IWMI conducted a scoping study to provide recent streamflow and water withdrawal data for water resources planning and management in the Lake Tana sub-basin, Ethiopia. The main aim of this working paper is to increase the focus on monitoring streamflow and water withdrawals including the provision of support to avail these data through collaboration with ABDO. The paper also highlights the pilot activities conducted on data monitoring, and coaching and mentoring of ABDO staff, and encouraging researchers to support the filling of data gaps. The paper also stresses the need for a data alliance.

Water-related Data

According to Laituri and Sternlieb (2014), “Water data” is a diverse set of information that address the physical, environmental, ecological, social, economic, cultural, and political parameters of water use, availability, and accessibility. Examples of water-related data types are listed in Table 1.

Table 1. Water-related data types relevant for water management planning and decision-making processes.

Atmosphere	Land	Socioeconomic
Rainfall	Surface water – river discharge, water level of rivers and lakes	Total population, population density, demography
Temperature – maximum and minimum, mean	Groundwater – water level and depth of wells	Gross domestic product (GDP) per capita, GDP annual growth rate, GDP from agriculture, industry and services
Evaporation	Quality of water in rivers and lakes, and groundwater	Agricultural labor force, total labor force
Wind speed	Land use and land cover (total land area, cropland, pastureland, forestland and woodland, irrigated land, other land uses)	
Relative humidity	Soil type, soil moisture	
Solar radiation	Topography, geology	
Weather forecasts (short term) Sub-seasonal predictions (medium term)	Water resources per capita, annual withdrawals for domestic, industrial and agricultural use	
Climate projections (long term)		

Source: Adapted from UNFCCC 2020.

Lake Tana Sub-basin

Located at the headwater of the Blue Nile (Abbay) River Basin in the northwestern highlands of Ethiopia, the Lake Tana sub-basin extends from 36.8° to 38.2° East (155 km) and from 11° to 12.8° North (200 km). It has a drainage area of about 15,321 km^2 and the lake covers about 3,000 km^2, which is 20% of the drainage area (Figure 1). The plains surrounding the lake form extensive wetlands during the rainy season providing considerable ecosystem services. The sub-basin supports fishing, hydropower, inter-basin water transfers to Tana Beles hydropower project, navigation, agriculture and tourism. Recent developments in the basin include booming small-scale irrigation, horticulture, industries, hotels, urbanization, and other sectors dependent on water resources of the sub-basin.

Climate

The mean annual rainfall of Lake Tana sub-basin is 1,280 mm (Setegn et al. 2008) with one main rainy season from June to September that accounts for more than 80% of the annual rainfall. The rest of the year is dry except for some rainfall during the March to May period. There are both spatial and temporal variations in rainfall. Spatially, the southern part of the sub-basin receives higher amounts of rainfall of about 1,850 mm/annum, on average. The eastern part receives the second highest amount of about 1,290 mm/annum. The northern and western parts of the sub-basin receive less rainfall – about 1,175 mm/annum and 1,070 mm/annum, respectively. Temporally, the year-to-year total rainfall variability is in the order of 16% while the seasonal variation is huge. There is also a direct relationship between elevation and rainfall amount with high rainfall occurring in the highlands.

The temperature of the sub-basin is, on average, about 20 °C with small seasonal changes unlike rainfall. Yet, the diurnal changes in temperature are large (Setegn et al. 2008). Potential evapotranspiration (PET) of the Lake Tana sub-basin is 1,400 mm per year, but shows an intra-annual variation with the maximum in April (150 mm per month) and minimum in August (82 mm per month). There are large spatial variations of PET in the sub-basin with about 1,260 mm per year in the southern part, 1,360 mm per year in the eastern part, and 1,510 mm per year in the northern and western parts. Hence, the annual excess water (precipitation – potential evapotranspiration) is 590 mm/annum in the southern part, -70 mm/annum in the eastern part, -335 mm/annum in the northern part and -440 mm/annum in the western part. This indicates that, with the exception of the southern part, the sub-basin is characterized by a moisture deficit.

Hydrology

There are four major rivers that feed Lake Tana and they account for 93% of the inflow (Kebede et al. 2006). These are Gilgel Abay, Gumara, Ribb and Megech rivers. Of these, the Gilgel Abay and Gumara rivers account for about 70% of inflow to the lake (Tigabu et al. 2020). In addition to these major rivers, Lake Tana receives runoff from more than 40 small rivers, most of which are concentrated in the western part of the lake with small catchments and intermittent flows (Dessie et al. 2015; Rientjes et al. 2011). Based on river flow data for the period 1990–2005 from the Ministry of Water, Irrigation and Energy (MoWIE), flow from June to September accounts for 82%–88% of annual flow while the dry season flow is only 12%–18% of annual flow.

Irrigation

Small-scale community managed irrigation schemes and farmer-led irrigation are increasingly common in the sub-basin with surface water irrigation dominant in the uplands and groundwater use in the plains around Lake Tana (Worqlul et al. 2015). The Koga large-scale irrigation project has been operational since 2010. Large-scale irrigation using dams to be constructed on the major rivers flowing into Lake Tana will cover

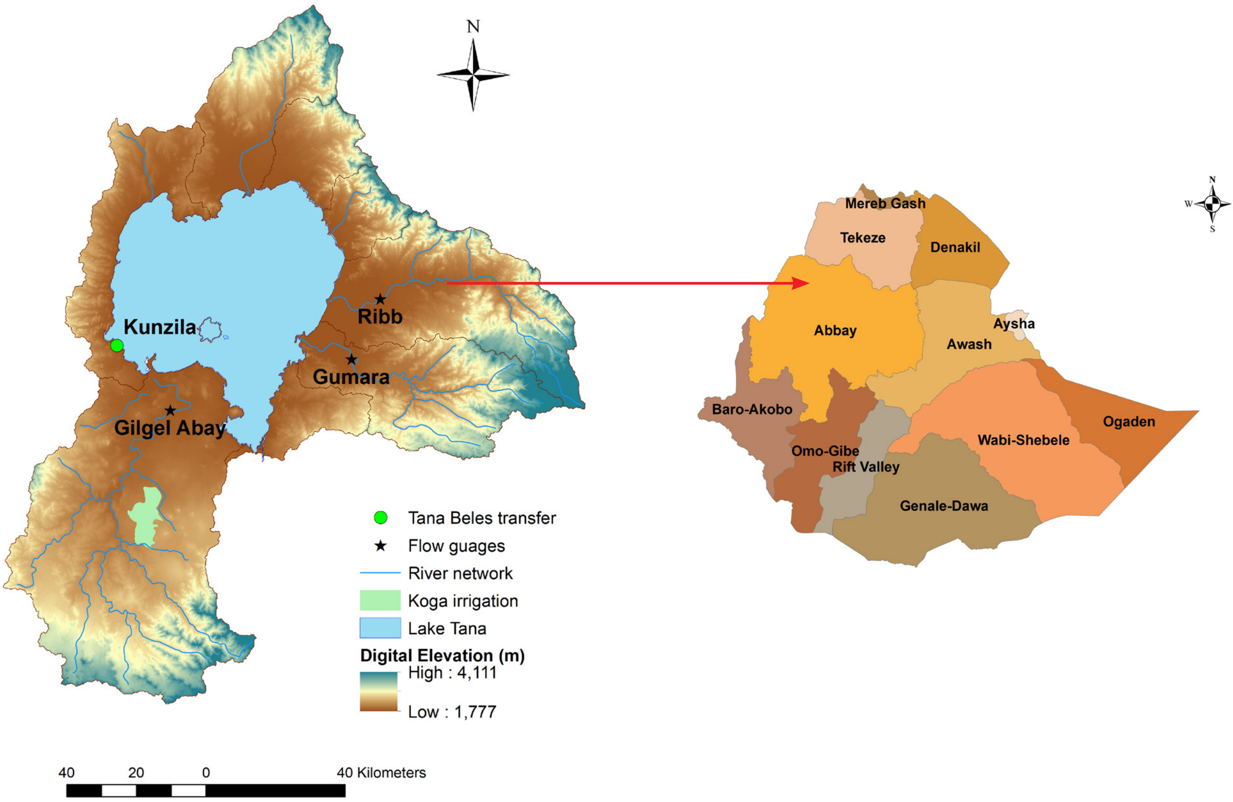

Figure 1. Location of Lake Tana sub-basin within Ethiopian river basins and three major streamflow gauging stations covered by this study.

61,853 ha, with an average annual water demand of 516 Mm^3 (McCartney et al. 2009) and an additional irrigated area of 17,500 ha which is planned through direct withdrawals from the lake (McCartney et al. 2010). The Megech-Seraba irrigation and drainage project that pumps water directly from Lake Tana is partially operational.

About 20% of the Lake Tana sub-basin is said to be suitable for surface irrigation, i.e., 130,508 ha (Worqlul et al. 2015). The average flow of Gilgel Abay and Gumara rivers is sufficient to irrigate the potential irrigable land in the dry season while that of Ribb and Megech rivers is insufficient and can only cover 50% and 35% of the potential irrigable area, respectively (Worqlul et al. 2015). Past research focused on potential irrigable land and estimation of water availability. However, there is limited information on actual irrigated area and water abstraction for irrigation.

The challenges to managing water resources in the Lake Tana sub-basin are given below:

- Increased water abstraction for agriculture.
- Degradation of wetlands and conversion to agricultural lands.
- Shift in cropping pattern to water-intensive crops.
- Water scarcity and conflicts among water users.
- Flooding and damage to infrastructure.
- Sedimentation and changes in river channel morphology.
- Trade-offs among sectors (hydropower, irrigation, tourism, navigation and fishing) – when more water is used for irrigation, less is available for the other sectors.
- Frequent changes to the organizational structure affecting hydrological data and services.
- Confusion about the institutional mandate and unclear data sharing protocols.

Streamflow Monitoring

Of the various challenges, we selected the issues related to streamflow monitoring. ABDO collects hydrological data from 171 manual gauging stations and 43 automatic stations in the Blue Nile Basin. ABDO took over monitoring and administration of the river gauging stations from MoWIE in 2015. Water level data are recorded on a daily basis using manual gauges during the morning and evening hours. During 2015, when responsibilities were transferred from MoWIE to ABDO, gauge height data were not recorded for 5-6 months.

On the other hand, measuring the velocity of river flow using current meter readings and sediment sampling are carried out three times per year to update the rating curve. This represents the high, medium and low flow periods. These data are used by university students and other interested organizations mostly for research purposes. ABDO's usual practice of measuring the velocity of river flow is more focused on ensuring that all rivers are covered. However, due to logistical constraints, it is usually difficult to cover all gauging stations in a timely manner.

During the peak flow season, velocity measurements are carried out once for each river. This indicates that when the technicians arrive at the river, they take the velocity measurement and continue their journey to the next river. This means that obtaining a high flow during their presence at the river is a matter of chance. This has implications in terms of not having enough measurements to develop reliable rating curves, i.e., changing stage values to discharge. Rating curves must be regularly updated due to man-made and natural changes that occur in these rivers. Table 2 shows some of the characteristics that contribute to changes in river morphology. Negatu et al. (2022) showed the stage-discharge relationships in these rivers over 60 years, which illustrated the significant impacts of changes in river morphology due to, for example, sediment load. Data presented in Negatu et al. (2022) are evidence for the need to update the rating curves as the discharge changed over the years for the same water level. Having the full range of possible and observed water levels and velocity is important to be able to capture flow ranges from peak flows to low flows and to have the best possible rating curve for a given time (5-10 years). However, velocity measurements taken by ABDO since 2016 do not cover the range of possible water levels and are found to be inadequate to establish rating curves for recent periods. Through this study, IWMI provided support to improve the temporal sampling of velocity measurements of the three main rivers (Gilgel Abay, Gumara and Ribb).

Data Collection Approach

Velocity Measurements in the Peak Flow Season

Gilgel Abay, Gumara and Ribb are the three major rivers selected for measuring velocity in the peak season. The gauging stations of these rivers cover about 90%, 82% and 66% of the Gilgel Abay, Gumara and Ribb catchments, respectively. The detailed characteristics of the gauging stations are given in Table 2.

Velocity measurements in the peak flow season are taken during the months of July and August. The discharge measurement was taken at the side bridge very close to the stations by a crane with a 75 pound (~34 kg) suspension weight. The approach used to improve the temporal sampling of velocity measurement is camping on one site for 10 days and measuring the velocity of the river twice, during the early morning and late afternoon hours. With this approach, 20 values of high flow data were obtained for one river over the 10-day period. The measurement periods were as follows:

- Gilgel Abay: July 9 – July 18, 2021
- Ribb: July 20 – July 29, 2021
- Gumara: July 31 – August 9,2021

The equipment used for the velocity measurement is a crane with a sounding cable, depth counter, suspension loads and AA type current meter (Figure 2). The team comprised of a senior technician, junior hydrologist and two technicians.

Table 2. Characteristics of the three major rivers in the Lake Tana sub-basin.

	Station 1	Station 2	Station 3
Station name	Gilgel Abay at Chimba	Gumara near Wereta	Ribb near Addis Zemen
Location	11.7062°N, 37.1684°E	11.8383°N, 37.6364°E	11.9939°N, 37.711°E
Catchment area	3,653 km^2	1,376 km^2	1,394 km^2
Establishment period	June 2005	June 1959	May 1959
Instrumentation	Staff gauges, telemetry	Staff gauges, telemetry	Staff gauges, telemetry
Site characteristics	Overflows after 6 meters to the floodplain River channel bed is boulders and stone	River channel bed is sandy and muddy	The road is too narrow and busy to take measurements ensuring proper safety to observers, the bank is eroded, and silted up to 3 m River channel bed is sandy and muddy Flooding damaged manual gauging station

Figure 2. The team taking velocity measurements using the equipment at Gilgel Abay gauging station (*photo*: Sitot Wassie).

The approach we used produced impressive results from different aspects. First, it provided 20 values per river for only the high flow season. Velocity measurements of such a high quality and quantity were not taken for the past five years. Figure 3 compares the measurements carried out in the past five years (2016–2020) with that of this study (wet season of 2021). In 2016, ten measurements were taken in Gilgel Abay and Gumara rivers (Figure 3). However, the number of measurements decreased after that and was zero in 2017 and 2019 for Gilgel Abay. Ribb had no measurement after 2016.

Second, camping on one site made it possible to obtain a good coverage of the peak to high flow range. This is important when developing rating curves. Also, the camping approach provided the opportunity for the data quality to be assessed in the field and the necessary adjustments to be made as needed.

Velocity Measurements in the Medium Flow Season

Velocity measurements in the medium flow season were carried out during the period October 12–29, 2021, with an interval of every three days. The discharge measurement was taken at the side bridge very close to the stations by a crane with a 75 pound suspension weight similar to that used to measure flows in the peak season. For the three rivers, a total of 36 discharge measurements, 12 from each gauging station, was collected. Only Gilgel Abay has measurements from 2016 to 2020 while Gumara has measurements from 2018 to 2020 (Figure 4). Measurements were not taken from Ribb during this time.

Velocity Measurements in the Low Flow Season

The field study was repeated for the low flow season in 2022 (from January 29, 2022 to February 8, 2022), so that data for all types of flow ranges are recorded and available for rating curve development. Figure 5 shows the very low number of velocity measurements taken by ABDO in the past years (2016–2021). In our field study, we took measurements from Gumara and Ribb rivers seven times and Gilgel Abay was measured four times. The water level during the low flow season does not change considerably within a day and there is hence no need to camp at the site for several days. Given that there is a gap in the velocity measurements during the low flow season by ABDO, this must be carefully considered if accurate rating curves are to be developed for these rivers.

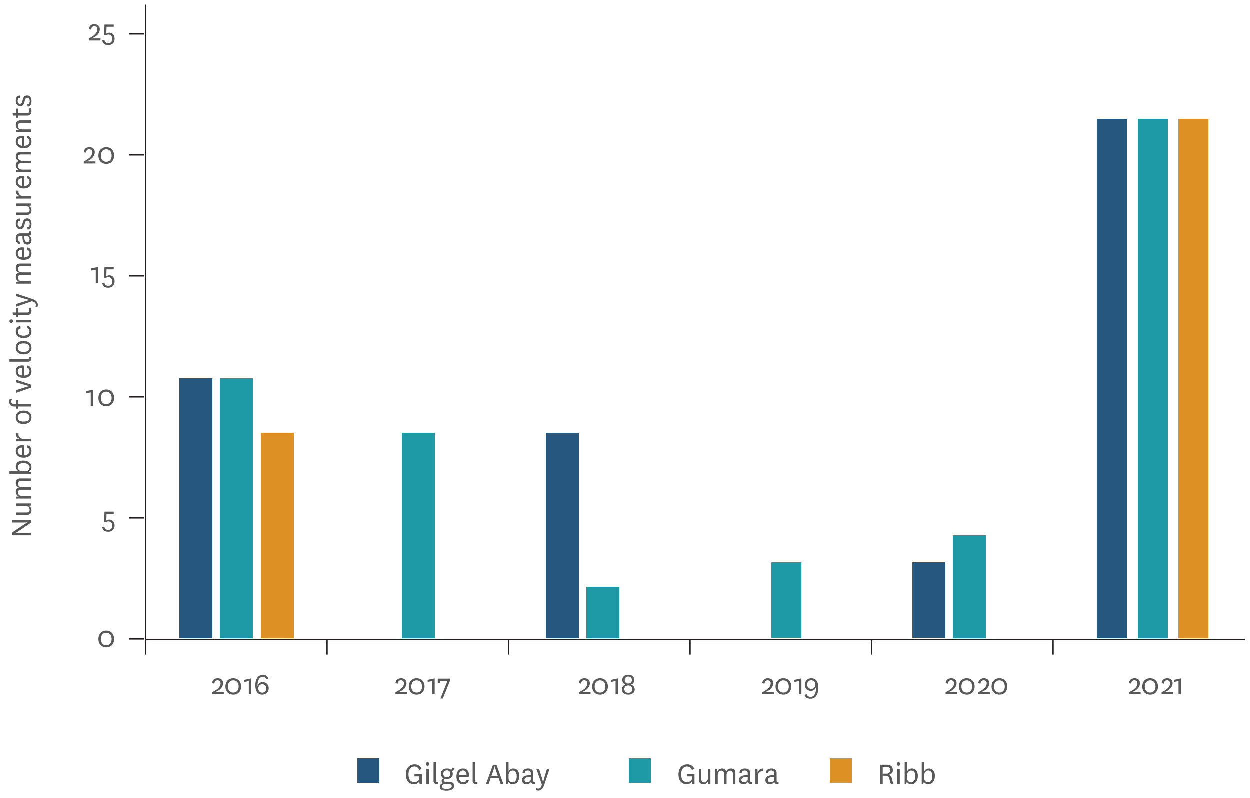

Figure 3. Comparison of the number of velocity measurements taken in three rivers (Gilgel Abay, Gumara and Ribb) during the high flow season (July-August) for the period 2016–2020 by ABDO and 2021 by this study.

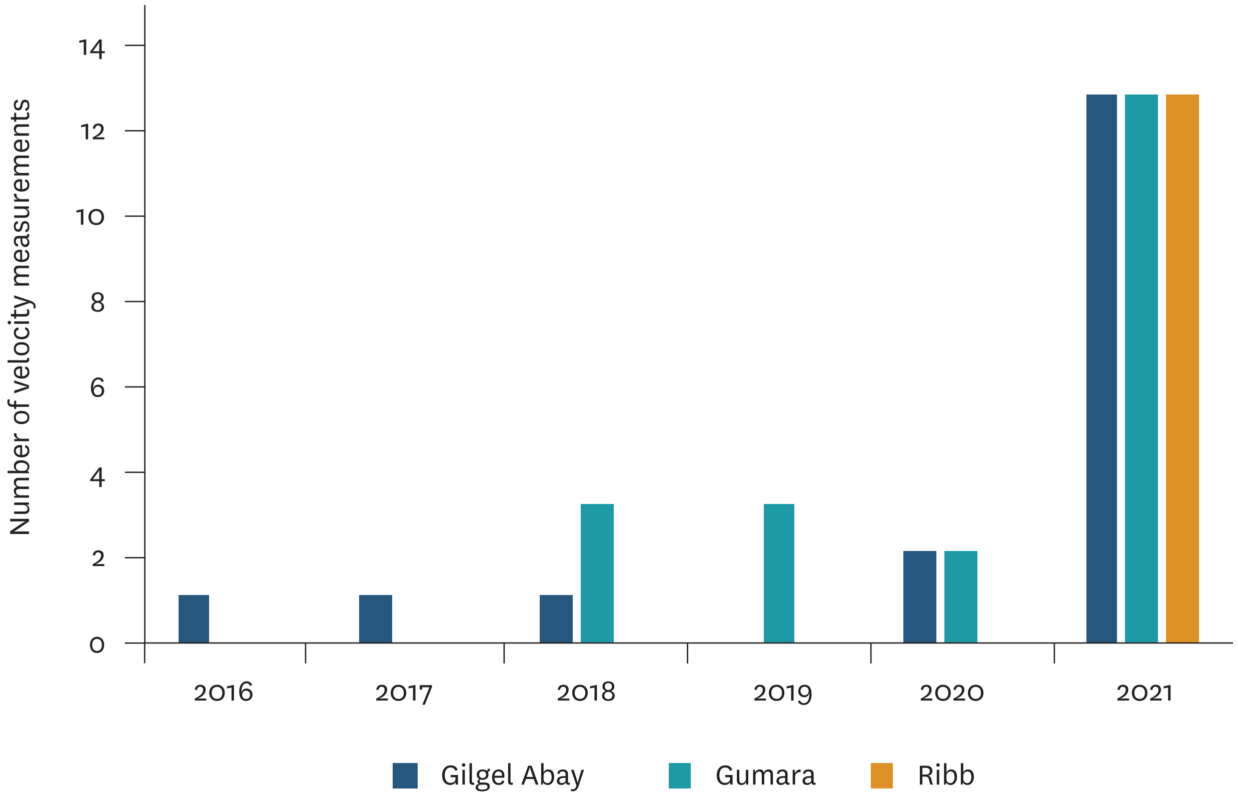

Figure 4. Comparison of the number of velocity measurements taken in three rivers (Gilgel Abay, Gumara and Ribb) during the medium flow season (mid-September to mid-November) for the period 2016–2020 by ABDO and 2021 by this study.

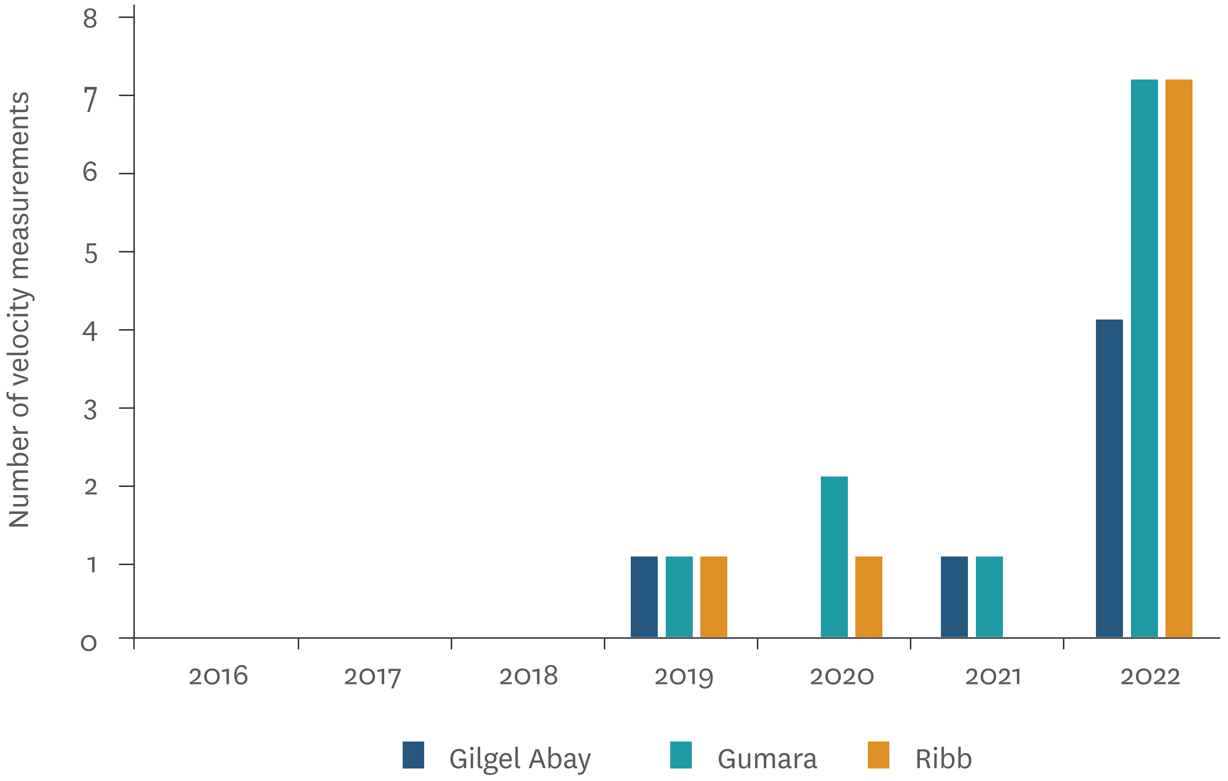

Figure 5. Comparison of the number of velocity measurements taken in the three rivers (Gilgel Abay, Gumara and Ribb) during the low flow season (January–March) for the period 2016–2021 by ABDO and 2022 by this study.

The lessons learned from this field study are as follows:

- To improve discharge data, the focus should be more on the quality and quantity of data from selected stations rather than trying to cover many rivers and taking only one measurement per season.
- This requires selecting some stations for one year and conducting several velocity measurements. For example, if 20 rivers are considered in a year and measurements are taken on five continuous days in each river, 60 rivers can be covered over 3 years.
- For measuring high flow, it is important to obtain a diverse range of velocities from rivers to provide accurate discharge data from gauge height measurements.
- Careful and strategic consideration should be given to low flow measurement to better estimate the baseflow and understand the change in datum.
- Engaging senior hydrology experts in the team enhances quality assurance.

Rating curve development is ongoing with ABDO staff receiving technical support from IWMI researchers. A study conducted by Negatu et al. (2022) showed that there has been a change in river morphology in the Lake Tana sub-basin over the years that warrants the need to carry out regular measurements and update the rating curves. In the sub-basin, erosion is dominant during the high flow season. It brings high sediment loads to these rivers and contributes to the change in river morphology. For instance, in Ribb River, sedimentation over many years resulted in the accumulation of about 3 m of sand close to the gauging station and buried it. In recent years, the community started sand mining in this location, which removes most of the sedimentation that occurred during the high flow season. In Gumara River, sedimentation over many years is estimated to be about 1 m at the gauging station. In Gilgel Abay, the riverbed has boulders and sedimentation is not expected to cause that much of a change in river morphology.

Monitoring Water Withdrawals

Developing a thorough knowledge of water resources within the Lake Tana sub-basin requires a better understanding of both water supply and water withdrawals. Information on water withdrawals from different sectors is not organized and compiled in a way that is suitable for water resources management. This study focused on producing baseline water withdrawal data for the Lake Tana sub-basin for the year 2020. This information will be relevant for research as well as for the water allocation model that ABDO is working on.

Data Collection Approach

This study surveyed the databases of *woredas*[2] that are within the Lake Tana sub-basin. There are about 20 *woredas* in the sub-basin and these were used for collecting data. The offices of different sectors were visited: agricultural offices (irrigation, fruit and vegetable directorate, and cereal directorate), livestock offices, water and energy offices, industry and investment offices, town industry and investment offices, town water supply and sanitation services, operational hydropower scheme (Tana Beles hydropower station), and operational irrigation schemes (Koga and Megech-Seraba irrigation schemes). The data collected from these offices were reviewed and organized in a way that is relevant for water management in each sector. These sectors include agriculture (rainfed, irrigated), horticulture, livestock, drinking water supply (town, rural), industry and hydropower.

Agriculture

Rainfed Versus Irrigation

The Lake Tana sub-basin utilizes both rainfed and irrigation systems for the production of cereal crops, vegetables and fruits. The area covered by rainfed agriculture is about 462,282 ha. This is comparable with the value of 450,000 ha for rainfed agriculture reported by Belete (2013). *Woredas* in the eastern part of the sub-basin, such as Farta and Fogera, have the highest rainfed agricultural area, covering about 25% of the total rainfed agricultural area of the sub-basin (Figure 6[a]). About 13% of the agricultural area is under irrigation during the dry seasons in the sub-basin. Considering two irrigation seasons for cereals and vegetables, the total irrigated area in the sub-basin is about 58,873 ha (Figure 6[b]). Five *woredas* have an irrigated area of more than 5,000 ha in the sub-basin. Fogera *woreda* has the highest irrigated area (10,895 ha) for two irrigation seasons (which is usually from October to January and February to May). The area ratio method is used for *woredas* that are on the border since water can flow both to the Lake Tana sub-basin and the adjacent sub-basins.

To estimate the amount of water withdrawals for irrigation, we conducted an experiment in 15 selected small-scale irrigation schemes. Monitoring was carried out on a daily basis during the dry season of 2020/21 for a period of

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[2] *Woreda* is the third-level administrative division of Ethiopia.

five months. The results of the experiment highlighted an average rate of 0.9 liters/second/ha of water use by the small-scale irrigation schemes (details of the experiment are provided in the section *Monitoring Water Withdrawals for Small-scale Irrigation*). Water used for irrigated and rainfed agriculture is, therefore, estimated using the 0.9 liters/second/ha withdrawal rate multiplied by the area under irrigation and rainfed agriculture. Although the rate is from an experiment in selected irrigated schemes, the same rate is used to determine water use in the rainfed area. This assumption can be revised if field experiments are carried during rainfed cultivation. With this estimation, water used for rainfed agriculture is observed to be the highest in the eastern part of Fogera and Farta *woredas*, southern part of Mecha *woreda*, and in the northern parts of Dembia and Gonder Zuria *woredas* (Figure 7).

Approximately 549 Mm^3 of water is withdrawn from both surface water and groundwater sources to irrigate an area of 58,873 ha per annum. From the total irrigated area, about 12% (7,096 ha) used groundwater while 88% (51,777 ha) used surface water. This translates to a water volume of 66 Mm^3/year from groundwater and 483 Mm^3/year from surface water. Fogera *woreda* has the highest irrigation water use of about 101 Mm^3/year followed by Mecha and Libo kemkem *woredas*. Withdrawals from groundwater will reduce baseflows that flow into the lake. The use of groundwater for irrigation will likely increase as more people shift from surface water use due to water scarcity.

Agricultural products such as fruits, coffee, khat and sugarcane are categorized under horticulture for this study. For such plants, about 4,958 ha of land is allocated in the sub-basin and cultivated mainly under irrigation and in selected *woredas*, under rainfed conditions. Mecha *woreda* has the highest horticultural activity under rainfed cultivation.

Livestock

The Lake Tana sub-basin has various types of animals under the livestock category. This study considered cattle, sheep, goats, equines and poultry. The total livestock population in the sub-basin, including these animals, is about 6,950,000. Both surface water and groundwater resources are used for livestock watering, but surface water sources are mainly used. Annual livestock water use is estimated to be about 31 Mm^3 based on consumption rate per head. From this total livestock water use, about 82% is consumed by cattle. The remaining 18% is used by sheep, goats, equines and poultry. Poultry accounts for the second largest share of livestock population after cattle, but they consume the least volume of water (0.24 Mm^3) due to their small water consumption rate per head. *Woredas* such as Mecha and Fogera have the largest population of livestock and associated water use (Figure 8). While this amount is relatively small compared to irrigation water use at the basin scale, for watersheds that experience water scarcity, there could be unmet water demand at the local level.

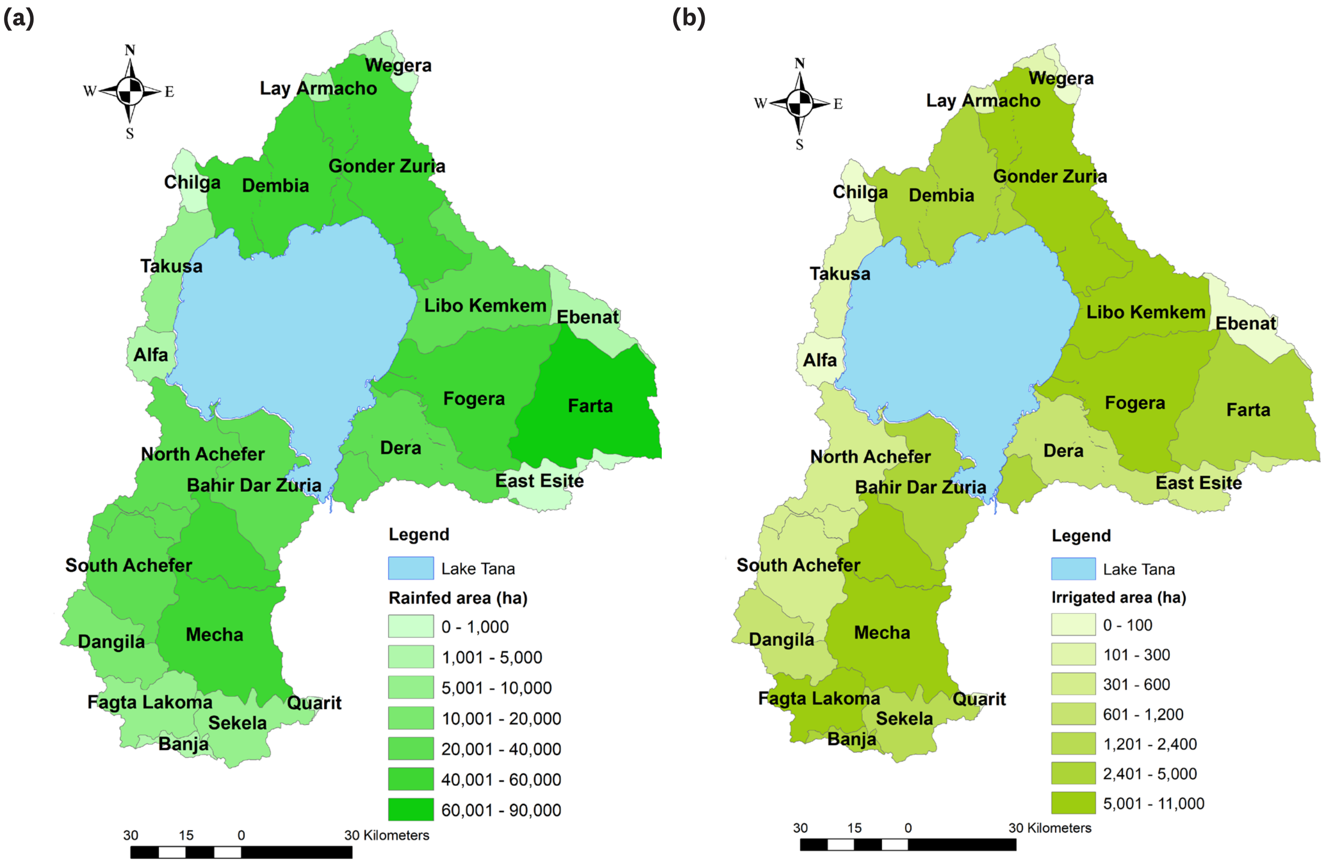

Figure 6. (a) Rainfed area, and (b) irrigated area in the Lake Tana sub-basin for two irrigation seasons where applicable.

Water for Drinking and Domestic Use

Urban Towns Versus Rural Settlements

The Lake Tana sub-basin has 23 towns including major regional towns such as Bahir Dar, Gonder and Debre Tabor. Groundwater is the main source of water supply in almost all the towns with 78% coverage, spring water is the second largest source with 18% coverage and the remaining 4% comes from surface water sources. There are 22 operational wells, 5 spring sources and one reservoir to provide water for Gonder town. Angereb reservoir is the main source of potable water for Gonder town (Getachew and Melesse 2012). Nigate et al. (2020) reported that, since 2002, Areke and Lomi springs have been supplying municipal water for Bahir Dar town and the Infranz springs are being constructed to provide additional water supplies. Depending on different operational times, the average water withdrawal rate from each town is multiplied by the total population of each town to obtain total water withdrawals for urban water use in the sub-basin. The total current yield or withdrawal rate is measured by each town in a *woreda*. Such estimates are important from the local user's perspective to understand the water available for each town.

About 23 Mm^3 of water is withdrawn from both surface water and groundwater sources for use in towns of the Lake Tana sub-basin. Towns such as Bahir Dar, Gondor and Debre Tabor use more water, and Bahir Dar is ranked first with annual water withdrawals of about 12.4 Mm^3/year (Figure 9[a]).

This study used a withdrawal rate of 25 liters/day/capita to estimate rural water use, which is a value provided in the Second Growth and Transformation Plan (GTP II) of Ethiopia. The total population in the Lake Tana sub-basin is estimated to be 1,866,115. Therefore, annual rural water use in the sub-basin is 17 Mm^3/year. Since a uniform water withdrawal rate is used to estimate rural water use, Figure 9[b] reflects the population of each *woreda*. Groundwater is the main source for the rural community's water supply. In some locations, the development of springs is common. Mecha *woreda* has the highest rural water use (3.4 Mm^3) in the sub-basin followed by Fogera *woreda* in line with their population (Figure 9[b]).

Water utilities have a record of the water produced annually and the amount of money collected based on water use (water bills), which helps to determine annual water use. The difference between the volume of water produced and the amount used is considered as water that is lost. In towns, water loss ranges from 38% to 15% depending on different towns and is based on values taken from the *woreda* database (Figure 10). An average of

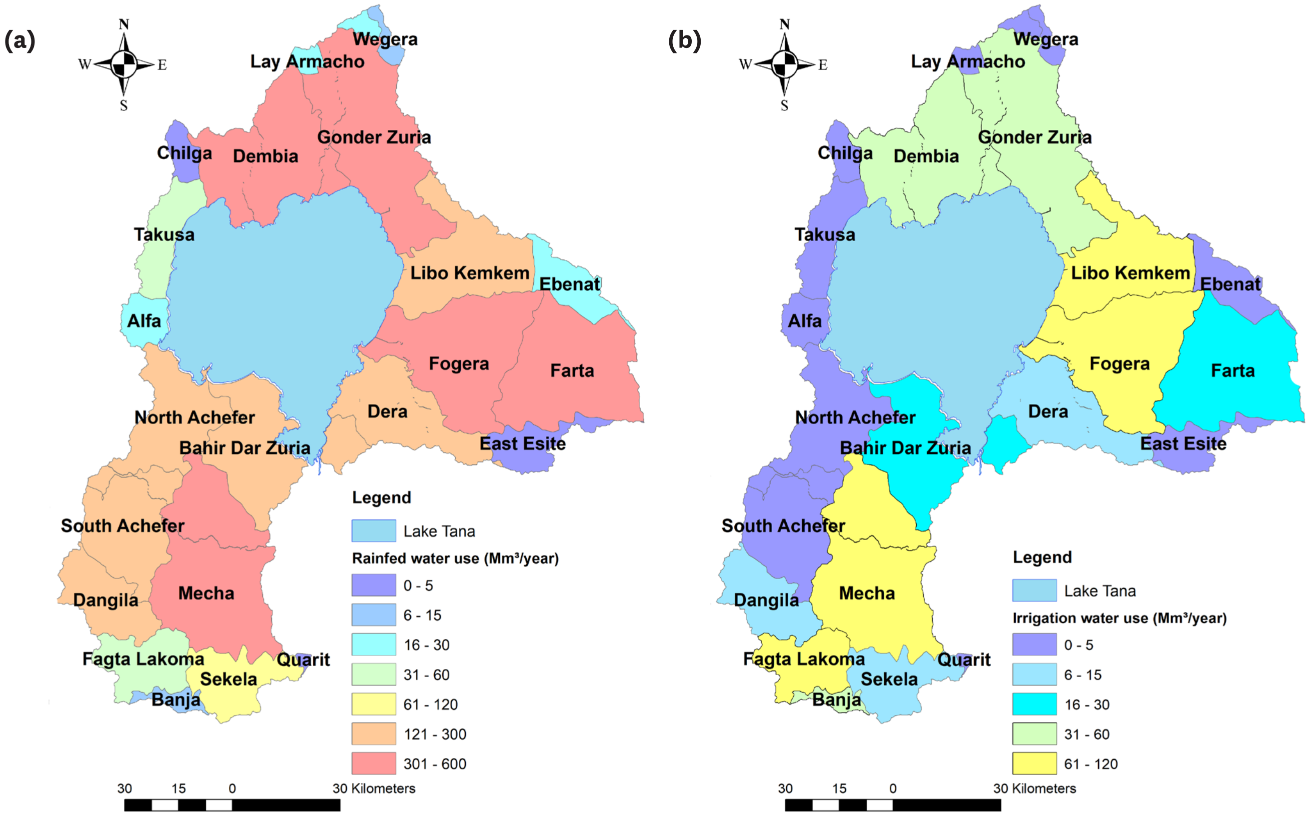

Figure 7. Water used for (a) rainfed agriculture, and (b) irrigation in the Lake Tana sub-basin for each *woreda*.

29.6% of water supplied to towns is lost due to different reasons, such as leakage and illegal water connections before the water meters. Therefore, from a total of 23 Mm^3 of water produced in towns, about 14.8 Mm^3 are distributed to users while about 6.8 Mm^3 are lost per annum. The amount of water supplied to Bahir Dar in 2009 was 5.9 Mm^3 (Admasu 2012), which is similar to the amount of water lost per annum in 2021 from the

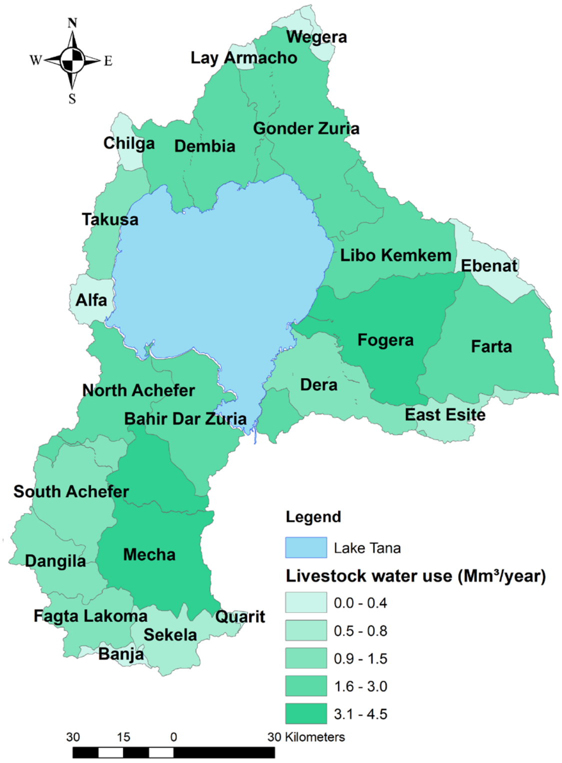

Figure 8. Estimated livestock water use per annum in the Lake Tana sub-basin for each *woreda*.

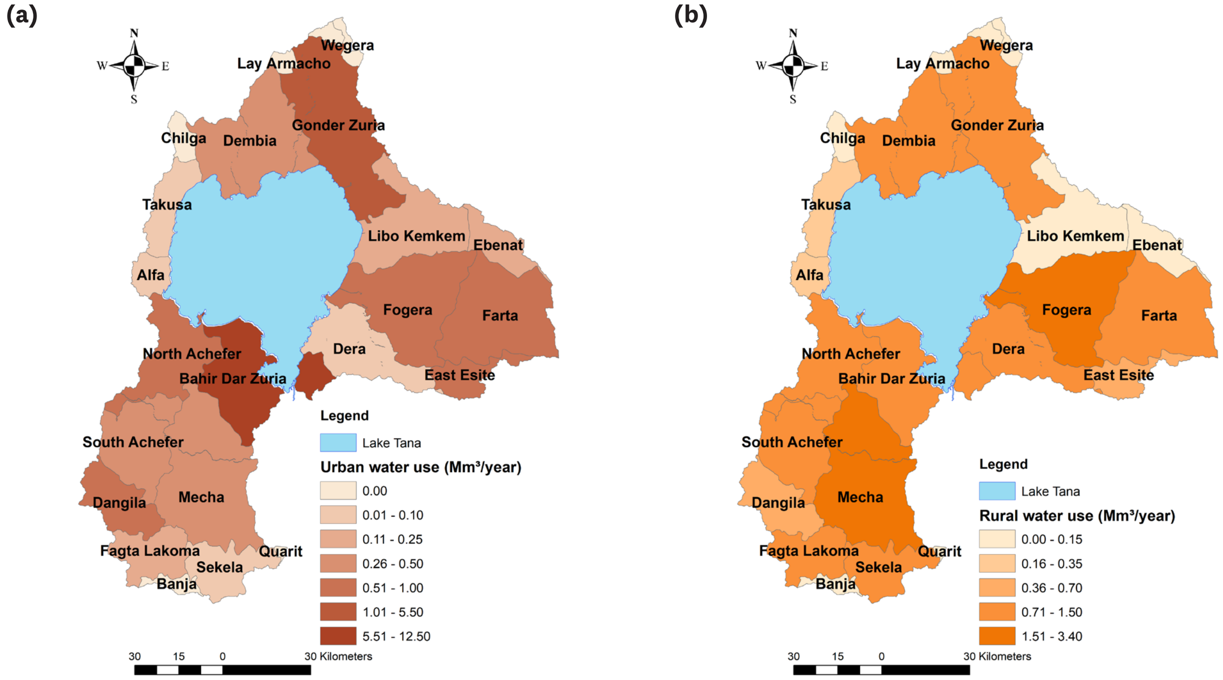

Figure 9. (a) Urban water use, and (b) rural water use in the Lake Tana sub-basin.

Lake Tana sub-basin. The 'lost' water may go back into the system if it is leakage loss. If water is used through informal (illegal) water connections before the water meters, this water is considered as 'lost' by water utilities while it was actually used by the people. The amount of water used by urban and rural water supply systems is small compared to the water used by the agriculture sector. However, understanding the supply to and loss from urban water systems is important for the water utilities that provide the water. It will help to estimate and reduce economic losses as they use pumping systems to provide the water. Given that urban water supply heavily depends on groundwater, having information on water use is helpful to protect groundwater resources from overextraction.

Industry

In Lake Tana sub-basin, water use in industries is not recorded and reported. During visits to *woredas*, 96 industries were found in the sub-basin. Most of the industries are concentrated in the big towns such as Bahir Dar (approximately 67%). Debre Tabor has the second largest number of industries (approximately 15%). The remaining industries are located in Wereta, Gonder and Dangila towns. This highlights that a large amount of water will be withdrawn by industries around Bahir Dar. Most industries use water from groundwater sources for production. However, this study could not estimate the amount of water withdrawn by industries because this information is nonexistent. Similar to other sectors, the amount of water used by industries might not be large when compared to the water used by the agriculture sector. However, when used water is returned to rivers and the lake, the potential for water quality deterioration due to pollution is a major concern for the Lake Tana sub-basin. From a quantity perspective, groundwater overextraction can be avoided if the amount of water used by industries is known.

Hydropower

The Lake Tana sub-basin has one major hydropower plant – Tana Beles – located in the North Achefer *woreda*, specifically in Kunzila rural town (see Figure 1). Water is diverted from the lake to the hydropower plant. Tesfaw (2016) stated that 70% of the lake's natural outflow to the Blue Nile River is diverted through a tunnel to Tana Beles hydropower plant. Although water is lost from the Lake Tana sub-basin, it returns to Blue Nile River through the Beles River after generating hydropower energy. The plant has four operational turbines with an average discharge of 38 m^3/s. The amount of water or discharge diverted from the lake for hydropower generation at full capacity is 160 m^3/s. There is a variation during the daytime and nighttime depending on the need for energy generation. Seasonally, the water diverted will differ depending on the required power generation and the operational rule of the reservoir or the Chara-Chara weir at the outlet of Lake Tana. The largest share of the water diverted in the sub-

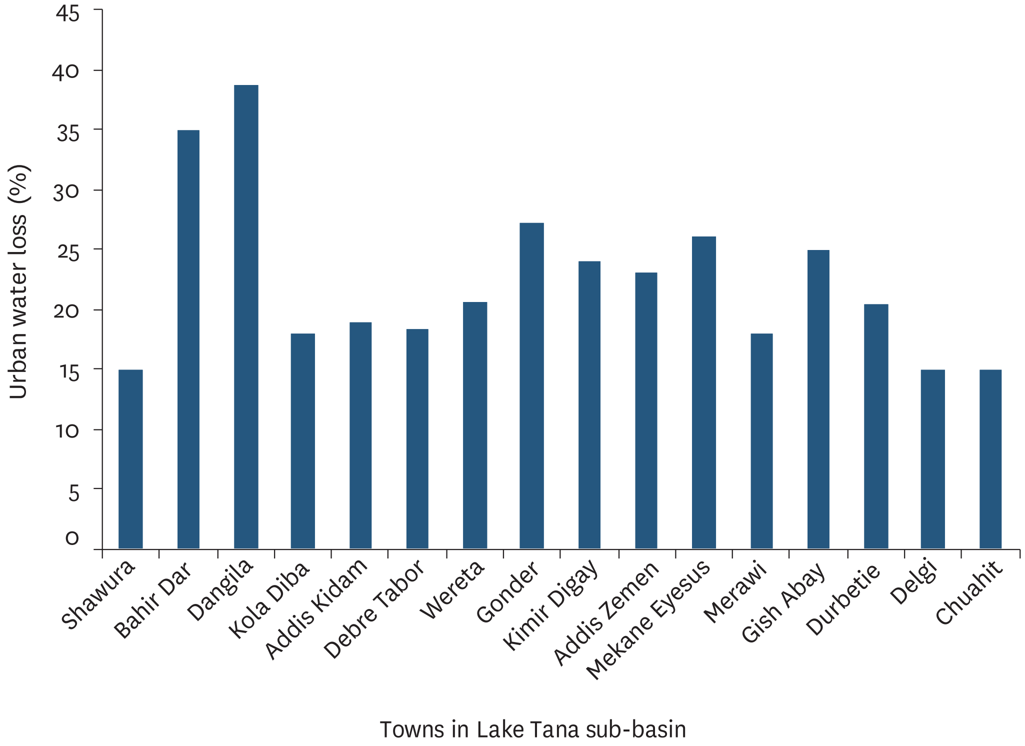

Figure 10. Urban water loss from each town in Lake Tana sub-basin.

basin is for hydropower generation (~2,522 Mm^3/year). With expanding agricultural activities, irrigation will be the second main water user in the sub-basin. Therefore, there is a need to monitor irrigation water withdrawals in the sub-basin. This study piloted the monitoring of water withdrawals for small-scale irrigation, which will be discussed in the next section.

Table 3 summarizes the water withdrawals per annum for the sectors that we could estimate. As can be seen, inter-basin water transfers account for the largest share of water withdrawals from the Lake Tana sub-basin. This water goes back to the Blue Nile River after generating electricity. However, for the Lake Tana sub-basin, it can be considered as water that has been used. Irrigated agriculture uses about one-fifth of the water used for inter-basin water transfers. In the current situation, the impact of irrigation water use is not yet high. However, when planned irrigation projects become operational, and with expanding small-scale irrigation, the amount of water used will increase. Hence, the need to monitor irrigation withdrawals for better water management.

The volume of water used by livestock, urban and rural water supply systems, and industries is very small compared to irrigation. Their impact at basin scale remains minimal. However, at the local scale, having information on water use is useful, especially for groundwater, which can face overextraction as it is the major source of water for industries and drinking purposes.

Table 3. Water withdrawals and water use by different sectors in the Lake Tana sub-basin based on data from the *woreda* offices.

Sector	Water withdrawals/use (Mm^3/year)	Assumption
Small-scale irrigated agriculture	549	0.9 liters/second/ha and 58,873 ha
Livestock	31	Livestock water consumption rate per head and total number of animals
Urban water supply	23	Average water withdrawal rate and total population of each *woreda*
Rural water supply	17	25 liters/day/capita and total population of 1,866,115
Hydropower – inter-basin water transfers to Tana Beles hydropower plant	2,522	160 m^3/s for 12 hours and 365 days

Monitoring Water Withdrawals for Small-scale Irrigation

This section is a summary adapted from Taye et al. (2021) on the impact of irrigation water withdrawals on the hydrology of Lake Tana sub-basin. Taye et al. (2021) stated that despite the booming irrigation activities in the sub-basin, limited information exists on the rate of irrigation expansion and its impact on the water balance of the sub-basin is unknown. Small-scale irrigation in Ethiopia is defined based on area coverage, which is less than 200 ha. In the Lake Tana sub-basin, small-scale irrigation is carried out using water from rivers through weirs and pumps. Those who depend on the weirs use water collectively and an area of up to 200 ha is irrigated. Others use individual pumps of a low capacity to pump water from rivers, with each farmer having approximately 1 ha of land. At times, there are multiple pumps being used to irrigate a larger area of land. In some locations, communal pumps with a high capacity are used to irrigate up to 40 ha. Water from shallow groundwater wells is also used for irrigation, mostly in the backyards of farm households. Through the monitoring of water withdrawals from rivers for use in small-scale irrigation, the study conducted by Taye et al.

(2021) estimated the amount of water used for irrigation during the dry season.

Fifteen small-scale irrigation schemes that utilize river water diversions were selected for monitoring water withdrawals. In these rivers, weirs were constructed to divert water from rivers to canals and then to the fields. The command areas in these locations range from 20 ha to 200 ha. Farmers use furrow irrigation for water applications and water is diverted from the rivers for 24 hours. Monitoring was carried out during the dry season from December 2020 to May 2021 on a daily basis using the float method. From the monitoring, it was identified that the average water withdrawal rate was 0.9 liters/second/ha after applying the correction factor for the float method overestimation of surface velocities. Farmers indicated that the amount of water diverted in these locations is insufficient, so we assumed there is no return flow.

Based on the data collected, water withdrawals for small-scale irrigation are about 430 Mm^3 per dry season (~50% of dry season flow) for one irrigation season. This value was estimated for an irrigation area of 38,694 ha, which was under small-scale irrigation in 2020/2021. These data were obtained through the collection and organization of smallholder irrigated area from databases of the *woredas* (districts) that are located within the Lake Tana sub-basin.

Surface water is the dominant source of water, and it provides about 80% of irrigation withdrawals in the sub-basin. The eastern part of the sub-basin faces water shortages as the dry season flow is insufficient for irrigation, whereas there is still scope for expanding small-scale irrigation in the southern part. Since water storage mechanisms are not yet fully developed in the sub-basin, irrigation water withdrawals during the dry season are causing water scarcity, environmental damage, and conflicts among water users. Water is more of a constraint than land for irrigation in the Lake Tana sub-basin if only rivers are used for irrigation, especially in the eastern part of the sub-basin.

With the prospects of irrigation expansion, water withdrawals for small-scale irrigation pose concerns of water scarcity at the local level and to the water balance of the sub-basin at large. Additionally, water losses without productive use are high with the current types of irrigation methods and irrigation infrastructure. Therefore, there is an urgent need for adaptive management of water withdrawals for small-scale irrigation and better water management practices since the potential impact on the (sub-)basin's hydrology will be large. The absence of a database that collects information on water withdrawals and attempts to create consolidated information is another aspect that can be improved by ABDO. This will be useful when making water management decisions.

Way Forward on Water Data for the Lake Tana Sub-basin

This section is based on discussions that took place during a workshop held in Bahir Dar, Ethiopia, in September 2021 and includes ideas of different professionals (Appendix, Workshop Participants). Figure 11 shows participants of the workshop during breakout group discussions. Three main topics were discussed in relation to water data monitoring, the use of data for water resources management and the establishment of a data alliance.

Figure 11. Experts discussing issues related to streamflow and water withdrawal data during a workshop breakout group discussion in September 2021 (*photos:* Meron Teferi Taye (left) and Rahel Mesganaw (right)).

Hydrological Monitoring

With regard to hydrological monitoring in the Lake Tana sub-basin, the following aspects are suggested to improve data collection, provide timely feedback to data collectors, and provide quality streamflow data:

- Hydrological data collection guidelines must be defined clearly and communicated to all stakeholders.
- If possible, improve payments, incentives and capacity of hydrological data observers, and assess their interests to motivate them to perform well in their jobs. This can be done by recognizing the significance of their job and giving them respect, which can help them to do their jobs with pride.
- Work on developing a sense of ownership and purpose for the data observers and providing timely feedback on the data collected. This includes creating awareness on the importance of hydrological data, because at times the data collected were never used.
- Design, implement and follow-up proper supervision of observers with both regular and surprise visits.
- Work on community awareness as it is required to avoid vandalism, and manipulated figures and meter readings.
- Develop a hydrological monitoring strategy and priority on short-, medium-, and long-term goals, focus areas, resource mapping, training needs, and observers training as well as community awareness strategies.
- Work on using the existing advanced systems such as the telemetry for better data collection through increasing attention to managing the system, and increasing awareness and useability of the data.

The following points are suggested to improve the frequency and timing of velocity measurement and regular updating of rating curves of rivers:

- One of the main constraints is the issue related to budget. During the high flow season, the Ethiopian budget year is in a time of transition as it ends in the month of June. Therefore, it is proposed that proper planning be carried out to ensure release of a timely budget or shifting the budget for this period or looking at different budget sources from other projects. This discussion can go up to the Ministry of Finance to avail relevant budget for measurements to be carried out in the high flow season.
- Increase skilled manpower on hydrology, and maximum utilization of available manpower at ABDO.
- Capacity building on measurement, data collection and analysis, rating curve development, use of regular structures, and camping approach for collecting main or important data on rivers.
- Role of universities in the Blue Nile Basin should be capitalized through partnership to support velocity measurement and rating curve development.
- IWMI's protocol used for this study can be used as a starting point to standardize the data collection format, and ensure data entry and database management are carried out in a timely manner.
- Assessment of existing data management/database initiatives.
- Sharing experiences among *woredas* on monitoring irrigation water withdrawals, including the establishment of a model (example) *woreda* for irrigation management that has a strong Water Users Association, which will be used to scale up experiences and activities to other *woredas* in the sub-basin.
- Provide training to *woreda* experts on creating awareness on the purpose of water withdrawal data, data collection and data management.
- Explore the option of using the citizen science approach to measure water levels of rivers, groundwater wells, and irrigation water withdrawals. Details on the use of citizen science are provided in Walker et al. (2019).
- Institutionalize the partnership between ABDO and *woredas* and plan together on data collection, organization and storage, including registering and updating the database of newly established irrigation schemes.
- ABDO to take the initiative and proactively coordinate to establish water use/abstraction and user database. It is suggested that ABDO should get involved in the primary data collection, including relevant trainings, database management and data storage.
- Water metering as an obligation for industrial and commercial uses and follow-up with ABDO.

Data Use for Water Resources Planning and Management

- Prepare metadata reports and refine the data required as input for the water resources planning model.
- Digitize data in Microsoft Excel with clear definitions of terms and parameters, which can be easily understood by users.
- Design the schematization of the WEAP model based on a participatory approach and understand the system by reviewing previous WEAP model schematizations.
- Use hydrological models such as HBV for streamflow estimation and use these values as input for the WEAP model.

- Involve hydrogeology experts who can contribute to integrating the groundwater system of the sub-basin.
- Provide training and capacity building on how to use the WEAP model, the schematization, and on integration with groundwater models.

Need for a Water Data Alliance

Given that we have started collecting data on water supply and demand, the workshop participants suggested the establishment of a water data alliance comprising interested organizations and water experts. This group of people and organizations should be interested in water data collection, sharing and quality control. ABDO can take the responsibility to initiate and follow-up with the alliance. The Appendix provides a list of workshop participants. This list can be used to identify members for the alliance. Information and experiences from other similar alliances in the country and worldwide can also be helpful. For instance, there is a multi-stakeholder platform for the Central Rift Valley and an agricultural water management task force for Ethiopia. Internationally, the Water and Development Alliance (WADA)[3] can be referred to as an example. Consultations should be held with stakeholders about the data alliance and the harmonization of data sharing must be discussed. Proactive data management and database gap identification can be discussed with all stakeholders in the initial brainstorming workshop of the data alliance.

Conclusions

Despite the Lake Tana sub-basin experiencing increasing development activities and future plans that require water for irrigation, hydropower, tourism and other sectors, there are significant gaps in water data for recent periods. Although there are data challenges, there is a possibility to solve this problem by using smart methods to collect data and develop partnerships. This study piloted how this can be done by engaging government entities at different levels. We have worked with *woreda* experts and ABDO staff to generate data and provide relevant data collection formats.

This paper demonstrates a systematic way of measuring river flow velocity to avail discharge data for recent years. This utilizes the water level data collected by ABDO and changes these data into a suitable format for water resources management. The study also demonstrated how irrigation water withdrawals can be monitored with relatively limited resources using community engagement (e.g., the citizen science approach); illustrated that experimental monitoring of canal discharge at a few sites can fill data gaps to estimate water withdrawals across the sub-basin in combination with information collected from literature; and showed the benefit of strengthening partnerships between data providers, e.g., ABDO, and data users, e.g., IWMI, to generate recent data that can be used as water resources information. This information is relevant to the investments that are being made in the sub-basin, research activities conducted by universities and research institutes, and the design and construction of irrigation schemes.

We do not believe that more data alone is a solution for every water resource problem. Rather, a systematic way of collecting data and focusing on major water users with appropriate monitoring frequency (e.g., 5 years for water withdrawals and river velocity) complemented by remote sensing data will help ABDO to provide up-to-date water resources information. The focus of this study is more on providing up-to-date information on river flows and water withdrawals, which has been a bottleneck to conducting research in the sub-basin.

We noticed that ABDO requires technical backstopping from national and international organizations to sustainably collect, store and manage water data. We have collaborated with a number of ABDO staff in data collection and analysis. These are young experts in water, irrigation and other sectors that have high potential for growth. Capacitating these young experts has the advantage of improving the collection and utilization of water data for the required purposes in the sub-basin. Universities that are situated within this sub-basin can be good partners to support the basin development office (ABDO). Experts in the sub-basin urged for the establishment of a data alliance with ADBO having a coordination role. This helps researchers and practitioners not only to use hydrological data but also to contribute to hydrological data collection, quality assessment, and management. However, ABDO requires strong support from researchers to develop the terms of reference for the data alliance.

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[3] https://www.globalwaters.org/wada

References

Abebe, W.B.; Tilahun, S.A.; Moges, M.M.; Wondie, A.; Derseh, M.G.; Nigatu, T.A.; Mhiret, D.A.; Steenhuis, T.S.; Van Camp, M.; Walraevens, K.; McClain, M.E. 2020. Hydrological foundation as a basis for a holistic environmental flow assessment of tropical highland rivers in Ethiopia. *Water* 12(2): 547. https://doi.org/10.3390/w12020547

Aboelnga, H. 2019. *Data is the new water: Data revolution to ensure no one is left behind and achieve SDG 6*. International Water Association (IWA) website, March 29, 2019. Available at https://iwa-network.org/data-is-the-new-water-data-revolution-to-ensure-no-one-is-left-behind-and-achieve-sdg-6/ (accessed April 7, 2022).

Admasu, W.F. 2012. *Infrastructural services (water supply and sewerage systems) - Problems and options for the provision and financing of it in Ethiopian cities: A case study on Bahir Dar City*. Paper presented at FIG Working Week 2012, Knowing to manage the territory, protect the environment, evaluate the cultural heritage, Rome, Italy, May 6-10, 2012.

Belete, M.A. 2013. *Modeling and analysis of Lake Tana sub basin water resources systems, Ethiopia*. PhD dissertation. University of Rostock, Germany.

Borgomeo, E.; Mortazavi-Naeini, M.; Hall, J.W.; Guillod, B.P. 2018. Risk, robustness and water resources planning under uncertainty. *Earth's Future* 6(3): 468–487. https://doi.org/10.1002/2017EF000730

Degefu, M.A.; Bewket, W. 2017. Variability, trends, and teleconnections of stream flows with large-scale climate signals in the Omo-Ghibe River Basin, Ethiopia. *Environmental Monitoring and Assessment* 189: 142 https://doi.org/10.1007/s10661-017-5862-1

Dessie, M.; Verhoest, N.E.C.; Pauwels, V.R.N.; Adgo, E.; Deckers, J.; Poesen, J.; Nyssen, J. 2015. Water balance of a lake with floodplain buffering: Lake Tana, Blue Nile Basin, Ethiopia. *Journal of Hydrology* 522: 174–186. https://doi.org/10.1016/j.jhydrol.2014.12.049

Dinku, T. 2019. Challenges with availability and quality of climate data in Africa. In: Melesse, A.M.; Abtew, W.; Senay, G. (eds.) *Extreme hydrology and climate variability: Monitoring, modelling, adaptation and mitigation*. pp.71–80. https://doi.org/10.1016/B978-0-12-815998-9.00007-5

Donauer, T.; Haile, A.T.; Goshime, D.W.; Siegfried, T.; Ragettli, S. 2020. *Gap and opportunity analysis of hydrological monitoring in the Ziway-Shala Sub-basin, Ethiopia*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 40p. (IWMI Working Paper 192). https://doi.org/10.5337/2020.210

Gebrehiwot, S.G.; Gärdenäs, A.I.; Bewket, W.; Seibert, J.; Ilstedt, U.; Bishop, K. 2014. The long-term hydrology of East Africa's water tower: Statistical change detection in the watersheds of the Abbay basin. *Regional Environmental Change* 14: 321–331. https://doi.org/10.1007/s10113-013-0491-x

Getachew, H.E.; Melesse, A.M. 2012. The impact of land use change on the hydrology of the Angereb Watershed, Ethiopia. *International Journal of Water Sciences* 1(4). https://doi.org/10.5772/56266

Goshime, D.W.; Absi, R.; Ledésert, B. 2019. Evaluation and bias correction of CHIRP rainfall estimate for rainfall-runoff simulation over Lake Ziway Watershed, Ethiopia. *Hydrology* 6(3): 68. https://doi.org/10.3390/hydrology6030068

Goshime, D.W.; Haile, A.T.; Rientjes, T.; Absi, R.; Ledésert, B. 2021. Implications of water abstraction on the interconnected Central Rift Valley Lakes sub-basin of Ethiopia using WEAP. *Journal of Hydrology: Regional Studies* 38: 100969. https://doi.org/10.1016/j.ejrh.2021.100969

Haile, A.T.; Akawka, A.L.; Berhanu, B.; Rientjes, T. 2017. Changes in water availability in the Upper Blue Nile basin under the representative concentration pathways scenario. *Hydrological Sciences Journal* 62(13): 2139–2149. https://doi.org/10.1080/02626667.2017.1365149

Haile, A.T.; Asfaw, W.; Rientjes, T.; Worako, A.W. 2022. Deterioration of Streamflow Monitoring in Omo-Gibe basin in Ethiopia. *Hydrological Sciences Journal*. https://doi.org/10.1080/02626667.2022.2060110

Josset, L.; Allaire, M.; Hayek, C.; Rising, J.; Thomas, C.; Lall, U. 2019. The U.S. water data gap—A survey of state-level water data platforms to inform the development of a national water portal. *Earth's Future* 7(4): 433–449. https://doi.org/10.1029/2018EF001063

Kebede, S.; Travi, Y.; Alemayehu, T.; Marc, V. 2006. Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *Journal of Hydrology* 316(1–4): 233–247. https://doi.org/10.1016/j.jhydrol.2005.05.011

Kedir, Y. 2021. The stumbling irrigation sector of Ethiopia: Critical review and analysis. *Irrigation & Drainage Systems Engineering* 10(3): 32021.

Laituri, M.; Sternlieb, F. 2014. Water data systems: Science, practice, and policy. *Journal of Contemporary Water Research & Education* 153(1): 1–3. https://doi.org/10.1111/j.1936-704X.2014.03174.x

Lakshmi, V.; Fayne, J.; Bolten, J. 2018. A comparative study of available water in the major river basins of the world. *Journal of Hydrology* 567: 510–532. https://doi.org/10.1016/j.jhydrol.2018.10.038

Larsen, M.A.D.; Petrovic, S.; Engstrom, R.E.; Drews, M.; Liersch, S.; Karlsson, K.B.; Howells, M. 2019. Challenges of data availability: Analysing the water-energy nexus in electricity generation. *Energy Strategy Reviews* 26: 100426. https://doi.org/10.1016/j.esr.2019.100426

McCartney, M.; Ibrahim, Y.A.; Sileshi, Y.; Awulachew, S.B. 2009. Application of the Water Evaluation and Planning (WEAP) Model to simulate current and future water demand in the Blue Nile. In: Awulachew, S.B.; Erkossa, T.; Smakhtin, V.; Fernando, A. (Comps.) *Improved water and land management in the Ethiopian highlands: Its impact on downstream stakeholders dependent on the Blue Nile. Intermediate Results Dissemination Workshop held at the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, February 5–6, 2009*. Colombo, Sri Lanka: International Water Management Institute (IWMI). pp.78-88. Available at https://publications.iwmi.org/pdf/H042509.pdf (accessed April 8, 2022).

McCartney, M.; Alemayehu, T.; Shiferaw, A.; Awulachew, S.B. 2010. *Evaluation of current and future water resources development in the Lake Tana Basin, Ethiopia*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 39p. (IWMI Research Report 134). https://doi.org/10.3910/2010.204

McCartney, M.P.; Girma, M.M. 2012. Evaluating the downstream implications of planned water resource development in the Ethiopian portion of the Blue Nile River. *Water International* 37(4): 362–379. https://doi.org/10.1080/02508060.2012.706384

MoA (Ministry of Agriculture). 2020. *Ten years development plan of agriculture sector*. Amharic version. Addis Ababa, Ethiopia: Federal Democratic Republic of Ethiopia, Ministry of Agriculture (MoA).

Mosello, B.; Calow, R.; Tucker, J.; Parker, H.; Alamirew, T.; Kebede, S.; Alemseged, T.; Gudina, A. 2015. *Building adaptive water resources management in Ethiopia*. Report. London, UK: Overseas Development Institute (ODI).

MoWIE (Ministry of Water, Irrigation and Energy). 2020. *Ten years development plan (2020/21-2029/30)*. Amharic version. Addis Ababa, Ethiopia: Federal Democratic Republic of Ethiopia, Ministry of Water, Irrigation and Energy (MoWIE).

Negatu, T.A.; Zimale, F.A.; Steenhuis, T.S. 2022. Establishing stage–discharge rating curves in developing countries: Lake Tana Basin, Ethiopia. *Hydrology* 9(1): 13. https://doi.org/10.3390/hydrology9010013

Nigate, F.; Van Camp, M.; Yenehun, A.; Belay, A.S.; Walraevens, K. 2020. Recharge–discharge relations of groundwater in volcanic terrain of semi-humid tropical highlands of Ethiopia: The case of Infranz Springs, in the Upper Blue Nile. *Water* 12(3): 853. https://doi.org/10.3390/w12030853

Nigussie, L.; Haile, A.T.; Gowing, J.; Walker, D.; Parkin, G. 2020. *Citizen science in community-based watershed management: An institutional analysis in Ethiopia*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 25p. (IWMI Working Paper 191). https://doi.org/10.5337/2020.207

Rientjes, T.H.M.; Perera, B.U.J.; Haile, A.T.; Reggiani, P.; Muthuwatta, L.P. 2011. Regionalisation for lake level simulation – the case of Lake Tana in the Upper Blue Nile, Ethiopia. *Hydrology and Earth System Sciences* 15: 1167–1183. https://doi.org/10.5194/hess-15-1167-2011

Setegn, S.G.; Srinivasan, R.; Dargahi, B. 2008. Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. *The Open Hydrology Journal* 2: 49–62. https://doi.org/10.2174/1874378100802010049

Taye, M.T.; Willems, P. 2012. Temporal variability of hydroclimatic extremes in the Blue Nile basin. *Water Resources Research* 48(3). https://doi.org/10.1029/2011WR011466

Taye, M.T.; Haile, A.T.; Fekadu, A.G.; Nakawuka, P. 2021. Effect of irrigation water withdrawal on the hydrology of the Lake Tana sub-basin. *Journal of Hydrology: Regional Studies* 38: 100961. https://doi.org/10.1016/j.ejrh.2021.100961

Taye, M.T.; Haile, A.T. 2021. *Declining data quality threatens water resources management in the Lake Tana sub-basin*. IWMI Blog, August 5, 2021. Available at https://www.iwmi.cgiar.org/2021/08/declining-data-quality-threatens-water-resources-management-in-the-lake-tana-sub-basin/ (accessed April 14, 2022).

Tesfaw, B.A. 2016. *The optimize operation and future development of Multi-purpose Tana-Beles Hydropower Project*. MSc Thesis, Norwegian University of Science and Technology, Trondheim, Norway.

Tigabu, T.B.; Hörmann, G.; Wagner, P.D.; Fohrer, N. 2020. Statistical analysis of rainfall and streamflow time series in the Lake Tana Basin, Ethiopia. *Journal of Water & Climate Change* 11(1): 258–273. https://doi.org/10.2166/wcc.2018.008

UN-Water. 2021. Monitor and report. UN-Water website. Available at https://www.unwater.org/what-we-do/monitor-and-report/ (accessed October 2021).

UNFCCC (United Nations Framework Convention on Climate Change). 2020. *Technical paper on data for adaptation at different spatial and temporal scales*. AC18/TP/7B. Bonn, Germany: Adaptation Committee. Available at https://unfccc.int/documents/254566 (accessed April 27, 2022).

UNSD (United Nations Statistics Division). n.d. *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*. Available at https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202021%20refinement_Eng.pdf (accessed December 2021).

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

WMO (World Meteorological Organization). 2021. WMO plan of action for hydrology consultations: Water management and support to SDG. Available at https://www.hydroref.com/wmo/hydrology/action-area-4-wra/ (accessed October 2021).

Worqlul, A.W.; Collick, A.S.; Rossiter, D.G.; Langan, S.; Steenhuis, T.S. 2015. Assessment of surface water irrigation potential in the Ethiopian highlands: The Lake Tana Basin. *Catena* 129: 76–85. https://doi.org/10.1016/j.catena.2015.02.020

Worqlul, A.W.; Ayana, E.K.; Maathuis, B.H.P.; MacAlister, C.; Philpot, W.D.; Osorio Leyton, J.M.; Steenhuis, T.S. 2018. Performance of bias corrected MPEG rainfall estimate for rainfall-runoff simulation in the upper Blue Nile Basin, Ethiopia. *Journal of Hydrology* 556: 1182–1191. https://doi.org/10.1016/j.jhydrol.2017.01.058

Appendix

Data Collection Formats

Continuous measurement of irrigation water withdrawals at main canals

		Type of canal	Rectangle
Kebele[4]	Gayeta	Canal bed material	Concrete
Woreda	Dangila	Travel distance (m)	10
River	Kuashni	Canal width (m)	0.63

Date	Time of the day	Travel time (seconds) and water depth (meters)								Wetted area (m²) and float velocity (m/s)		
		First run		Second run		Third run		Average				
dd/mm/yyyy		Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)	Time (s)	Depth (m)	Area	Velocity	Discharge (m^3/s)
21/11/2020	Morning	14.00	0.44	12.00	0.42	12.00	0.43	12.67	0.43	0.27	0.79	0.2139
	Evening	13.00	0.45	12.00	0.43	13.00	0.42	12.67	0.43	0.27	0.79	0.2155
22/11/2020	Morning	12.00	0.45	13.00	0.44	14.00	41.00	13.00	13.96	8.80	0.77	6.7668
	Evening	15.00	0.42	13.00	0.44	14.00	0.44	14.00	0.43	0.27	0.71	0.1950
23/11/2020	Morning	11.00	0.44	11.00	0.42	14.00	0.42	12.00	0.43	0.27	0.83	0.2240
	Evening	15.00	0.41	13.00	0.42	14.00	0.44	14.00	0.42	0.27	0.71	0.1905
24/11/2020	Morning	14.00	0.43	13.00	0.43	14.00	0.44	13.67	0.43	0.27	0.73	0.1998
	Evening	12.00	0.43	13.00	0.43	12.00	0.43	12.33	0.43	0.27	0.81	0.2196
25/11/2020	Morning	12.00	0.42	14.00	0.42	13.00	0.43	13.00	0.42	0.27	0.77	0.2052
	Evening	11.00	0.44	12.00	0.45	12.00	0.44	11.67	0.44	0.28	0.86	0.2394
26/11/2020	Morning	13.00	0.44	12.00	0.44	12.00	0.45	12.33	0.44	0.28	0.81	0.2265
	Evening	12.00	0.45	13.00	0.44	12.00	0.43	12.33	0.44	0.28	0.81	0.2248
27/11/2020	Morning	13.00	0.45	12.00	0.45	13.00	0.44	12.67	0.45	0.28	0.79	0.2222
	Evening	11.00	0.44	13.00	0.44	12.00	0.44	12.00	0.44	0.28	0.83	0.2310
28/11/2020	Morning	13.00	0.45	11.00	0.44	13.00	0.45	12.33	0.45	0.28	0.81	0.2282
	Evening	11.00	0.43	13.00	0.45	13.00	0.43	12.33	0.44	0.28	0.81	0.2231

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[4] *Kebele* is the smallest administrative unit of Ethiopia.

FLAIR Project: Workshop Schedule

Workshop Day 1

Date	**September 21, 2021**
8:30-9:00	Registration and opening
9:00-10:30	Introduction to the FLAIR project – Dr. Meron Teferi Taye (IWMI)
	Presentation on Abbay Basin Telemetry Hydrological/Basin Information System (HIS/BIS) – Mr. Mamaru Talema (ABDO)
10:30-10:45	Break
10:45-12:30	Presentation on hydrological monitoring in Ethiopia from IWMI's perspective – Dr. Alemseged Tamiru Haile (IWMI)
	Presentation on improving the temporal sampling of velocity measurement for rating curve development in the main rivers of Lake Tana sub-basin – Mr. Yaregal Geremew (ABDO)
12:30-14:00	Lunch
14:00-15:30	Group work: Opportunities to improve hydrological data monitoring
15:30-15:45	Break
15:45 -17:00	Group work: Reporting back on opportunities to improve hydrological data monitoring

Workshop Day 2

Date	**September 22, 2021**
8:30-9:00	Recap of Day 1
9:00-10:30	Introduction to ABDO structure and mandates – Mrs. Addisalem Genet (ABDO)
	Presentation on small-scale irrigation water abstraction data measurement - Mrs. Addisalem Genet (ABDO)
10:30-10:45	Break
10:45-12:30	Presentation on irrigation expansion and implications for water resources in Lake Tana sub-basin – Dr. Abebech Abera (Bahir Dar University)
	Presentation on the effect of irrigation water withdrawals on the hydrology of the Lake Tana sub-basin – Dr. Meron Teferi Taye (IWMI)
12:30-14:00	Lunch
14:00-15:30	Group work: How to sustain the data collection approach presented and its importance (experience sharing)
15:30-15:45	Break
15:45 -17:00	Group work: Reporting back on how to sustain the data collection approach presented and its importance

Workshop Day 3

Date	**September 23, 2021**
8:30-9:00	Recap of Day 2
9:00-10:30	Baseline and projected water stress of Lake Tana sub-basin - Mrs. Tinebeb Yohannes (World Resources Institute)
	Current water abstraction and demand by various sectors in Lake Tana sub-basin – Mr. Bewuketu Abebe (ABDO)
10:30-10:45	Break
10:45-12:30	Assessment of water demand and water resource reliability in the Lake Tana sub-basin using the Water Evaluation and Planning (WEAP) model – Mr. Bahiru Alemayehu (ABDO)
	Group work: How to use water abstraction data for water allocation and what to improve
12:30-14:00	Lunch
14:00-15:30	Group work: Reporting back on how to use water abstraction data for water allocation and what to improve
15:30-15:45	Break
15:45-17:00	Closing of workshop and settlement of expenses

Workshop Participants

No.	Title	Name	Institute
1	Dr.	Meron Teferi Taye (F)	International Water Management Institute (IWMI)
2	Dr.	Alemseged Tamiru Haile	IWMI
3	Mr.	Yewondwosen Mengistu	Abbay Basin Development Office (ABDO)
4	Mrs.	Addisalem Genet (F)	ABDO
5	Mr.	Yaregal Geremew	ABDO
6	Mr.	Sitot Wassie	ABDO
7	Mr.	Fentahun Worku	ABDO
8	Mr.	Selamsew Birhane	ABDO
9	Mr.	Bewuketu Abebe	ABDO
10	Mr.	Bahiru Alemayehu	ABDO
11	Mr.	Addisu Mulu	Dangila *woreda* office
12	Mr.	Derege Bamlaku	Fogera *woreda* office
13	Mr.	Girmachew Addisu	IRC WASH
14	Dr.	Abebech Abera (F)	Bahir Dar University
15	Dr.	Mulugeta Azeze Belete	Bahir Dar University
16	Dr.	Sirak Tekleab	Hawassa University
17	Dr.	Behailu Birhanu	Addis Ababa University
18	Mrs.	Tinbeb Yohannes (F)	World Resources Institute (WRI)
19	Dr.	Zablon Adane	WRI
20	Mr.	Mamaru Talema	ABDO
21	Mr.	Tadesse Getachew	Ministry of Water, Irrigation and Energy (MoWIE)

Note: F – Female.

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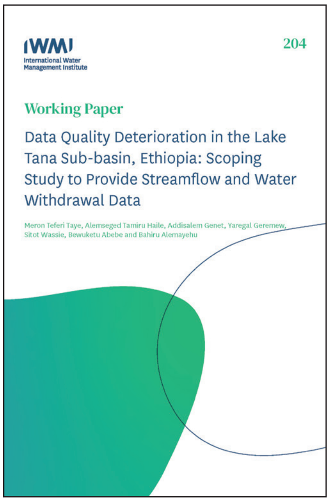

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Data Quality Deterioration in the Lake Tana Sub-basin, Ethiopia: Scoping Study to Provide Streamflow and Water Withdrawal Data

Meron Teferi Taye, Alemseged Tamiru Haile, Addisalem Genet, Yaregal Geremew, Sitot Wassie, Bewuketu Abebe and Bahiru Alemayehu

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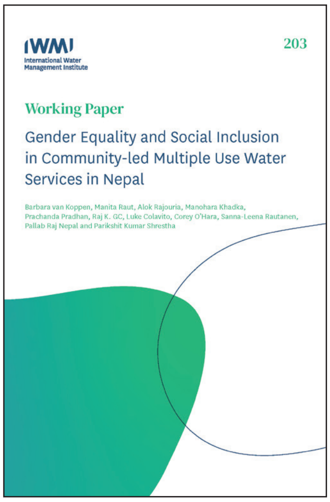

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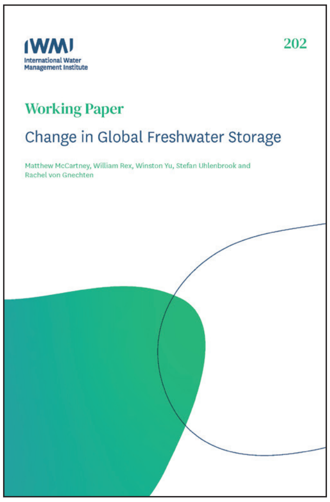

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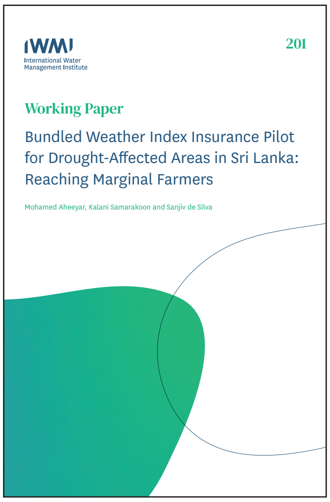

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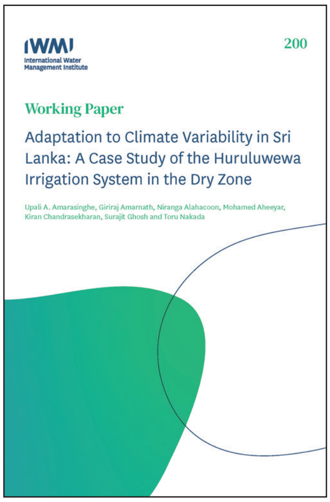

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