Monitoring Water Withdrawal and Streamflow Data for Effective Water Resources Management in Lake Tana Sub-Basin

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Abstract

The Lake Tana sub-basin is one of Ethiopia's growth corridors with plans that include irrigation expansion. Despite the basin's expanding irrigation activity, there is little information on the rate of irrigation expansion, water withdrawal for irrigation and its impact on the sub-basin's water resources. This study focused on monitoring irrigation water withdrawal from small-scale irrigation schemes and the spatial variation of streamflow in the Gumara River, a major tributary to Lake Tana. For the irrigation water withdrawal monitoring small-scale irrigation schemes from seven districts that use river water diversions were chosen. The command areas of these irrigation schemes range from 20 to 200 ha of land. The monitoring was conducted for two years during the dry season when irrigation activities are dominant. Spot discharge measurements for Gumara River were done at seven locations on the main river at downstream and its tributaries at upstream. The results show that irrigation water withdrawals can range on average from 559 m^3 day^{-1} to 17824 m^3 day^{-1} at different schemes. The amount of water diverted mostly correlates with the size of the irrigated area and the size of the rivers. However, at some locations inefficient use of water was observed as the amount of water diverted was large for a relatively smaller irrigated area. The eastern part of the basin experiences lots of irrigation. The Gumara River at different locations showed water scarcity problem. At the downstream within a few kilometres difference between two locations where spot measurements were taken the discharge dropped by 2.8 m^3/s during medium flow season. This suggested that there is substantial irrigation practice along the Gumara River, which was also confirmed through irrigation sites survey. Therefore, this study promotes monitoring irrigation water withdrawals and streamflow data at different locations to better manage the sub-basins water resources and avoid localized water scarcity.

Keywords: Irrigation Withdrawal, Streamflow, Monitoring, Spot Measurement, Lake Tana, Gumara

1. Introduction

The Lake Tana sub-basin is one of Ethiopia's growth corridors with plans that include irrigation expansion. Small-scale community managed irrigation schemes and farmer-led irrigations are becoming 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). Arguably, changes in irrigation use are more recent phenomena especially in the last 10-15 years where irrigation activities are slowly getting attention and acceptance by farmers. Small-scale irrigation promotion by donors, non-governmental organizations and local governments is substantially supporting irrigation expansion in the sub-basin. Communities are benefiting from the expanding irrigation use with their livelihoods showing improvement (Ayele *et al*., 2013). However, Kassie and Alemu, (2021) states that there is still work to be done to convert the increased income from irrigation to food security of the households.

In terms of irrigated area, Abera *et al*., *(2020)* used remote sensing to show that irrigated area increased from 84,900 ha in 2006 to 121,400 ha in 2016. Although the estimated area coverage requires verification, it shows the undeniable expansion of irrigation in the last decade. Worqlul *et al*., *(2015)* estimated about 20% of the Lake Tana sub-basin as suitable for surface irrigation, i.e., 130,508 ha. They indicated that while the average flow of Gilgel Abay and Gumara rivers is sufficient to irrigate the potential irrigable land in the dry season that of Ribb and Megech is not sufficient and can only cover 50% and 35% of potential irrigable area, respectively. With this, Gilgel Abay has the largest potential area for surface irrigation and Megech has the smallest potential area (Worqlul *et al*., 2015).

Given this large potential, in recent years the use of irrigation during the dry season is increasing. Irrigation by small scale farmers cover more area than the large-scale irrigation schemes at Koga (fully operational) and Megech-Seraba (partially operational). Despite the basin's expanding irrigation activity, there is little information on the rate of irrigation expansion, water withdrawal for irrigation and its impact on the sub-basin's water resources. Taye *et al., (2021)* showed the use of water for irrigation is causing water scarcity in the Gumara catchment, a major tributary to Lake Tana.

This study extended the information gathered in Taye *et al., (2021)* on daily irrigation water withdrawn from rivers during dry season on selected sites of the sub-basin. The study also attempted to understand the spatial streamflow amount differences in connection with irrigation water withdrawal in Gumara catchment. This necessitated data collection at multiple spots of the Gumara River and its tributary rivers. The objective of this study is therefore to promote monitoring irrigation water withdrawals and streamflow data at different locations to better manage the sub-basins water resources and avoid local water scarcity issues.

2. Methodology

2.1 Study Area

Lake Tana sub-basin is located at the headwater of the Blue Nile (Abbay) river basin, in the North-western Ethiopia highlands (Figure 1). The sub-basin has area of about 15,321 km^2 out of which about 3000 km^2 is covered by the lake. 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. 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). Annual rainfall can be above 2000 mm and on the lower side it can be around 800 mm (Figure 1). The mean annual rainfall is estimated as 1280 mm (Setegn *et al.* 2008). There is one major rainy season from June to September. The rest of the year is dry with small rainfall amount during March to May.

The main livelihood of the sub-basin is agriculture. Consequently, about 67% of the sub-basin area is used by smallholder farmers for rain-fed crop production (Abera *et al*., 2020). Irrigation occurs during the November to May period in different parts of the sub-basin. This study selected small-scale irrigation schemes from seven districts for daily monitoring of irrigation water withdrawal. The locations of schemes are as shown in Figure 1. The details of the schemes' characteristics are given in Table 1. All these schemes are used by farmers for irrigation using furrow irrigation system. Most of these canals are lined except at two locations (Serja and Zuma, Figure 1 or Table 1).

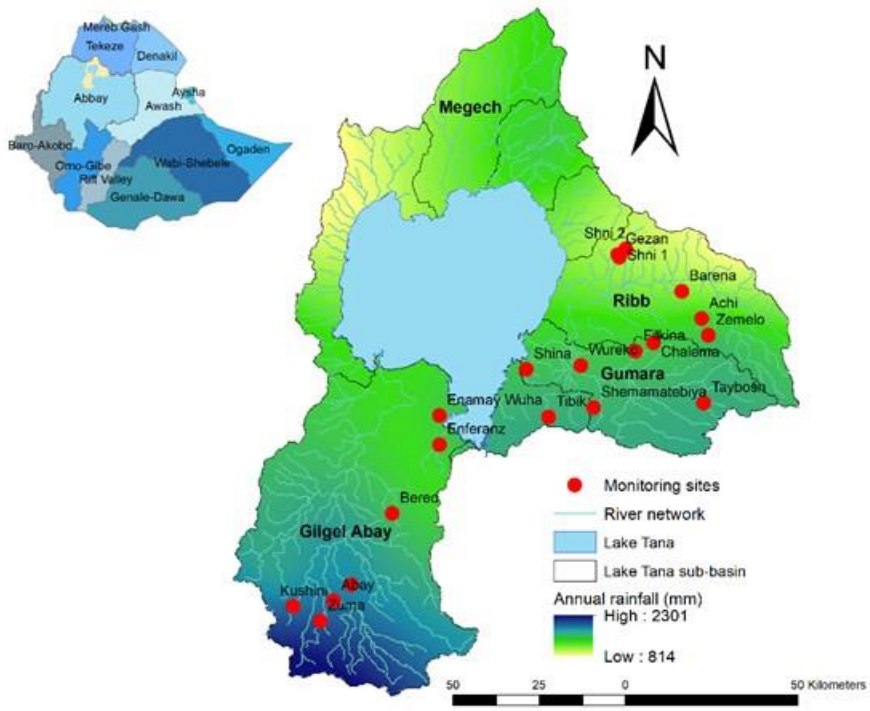

Figure 1. Lake Tana sub-basin and small-scale irrigation schemes used for water withdrawal monitoring

Table 1. Irrigation schemes considered in irrigation water withdrawal monitoring in the dry season of 2020-2022. December 2020 to May 2021, designated as Year 1 and November 2021 to May 2022 as year 2. Y1 refers to year 1 and Y2 refers to year 2

No	District	Kebele	River name	Irrigated area (ha)	Monitoring year
1	Dangila	Afesa	Zuma	35	Y1, Y2
2	Dangila	Gayeta	Kuashini	200	Y1, Y2
3	Dangila	Wumbri	Abay	80	Y1
4	Dangila	Zelesa	Asher	25	Y2
5	North Mecha	Enamert	Bered	53	Y1, Y2
6	North Mecha	Dagi	Serja	59	Y1, Y2
7	North Mecha	Goragot	Goguwuha	20	Y1, Y2
8	Fogera	Hagereselam	Silkena	100	Y1, Y2
9	Fogera	Wotemb	Barena	40	Y1, Y2
10	Fogera	Bebeks	Wureko	61	Y1
11	Fogera	Chalema	Wondegri	50	Y2
12	Fareta	Aybaniba	Achi	48	Y1
13	Fareta	M/Tsion	Taybosh	60	Y1
14	Fareta	Terraroch	Zimelo	56	Y1
15	Bahirdar Zuriya	Wogelesa	Enferanz	157	Y1, Y2
16	Bahirdar Zuriya	Selecha	Enferanz	64.5	Y1, Y2
17	Bahirdar Zuriya	Wonjeta	Enamaywuha	48.5	Y1, Y2
18	Dera	Tebabari	Shemamatebiya	146	Y2
19	Dera	Kulala	Tibik	70	Y2
20	Dera	Wagera	Shina	101	Y2
21	Libo kemkem	Addis zemen 04	Shini 1	95	Y2
22	Libo kemkem	Angot	Shini 2	60	Y2
23	Libo kemkem	Gizana	Gezana	115	Y2

2.2 Irrigation Water Withdrawal Measurement

For the irrigation water withdrawal monitoring small-scale irrigation schemes from seven districts that use river water diversions were chosen. The command areas of these irrigation schemes range from 20 to 200 ha of land (Table 1). In each district three rivers were considered for measurement. The water withdrawal monitoring was conducted by district and *kebele* level experts for two dry season periods.

These periods were December 2020 to May 2021, designated as Year 1 and November 2021 to May 2022 designated as Year 2 hereafter.

In Year 1, only 15 schemes were monitored from five districts and in the second year 19 schemes were considered from seven districts. The difference in the number of schemes in the two years occurred because of the difference in the level of support obtained from the district level experts in the two years. Also, there was a security challenge in different districts in either of the years. In Year 2 learning from the previous year experience additional two districts (Dera and Libo kemkem) were considered while one of the districts (Fareta) from the Year 1 was dropped.

Experts were identified from each *kebele* who could measure the canal velocity at daily basis. They were supervised by the district agriculture or irrigation experts. On-site training was given for data observers and supervisors before the start of data collection. The training was mainly focused on how to use float method for velocity measurement and the use of data collection form prepared by this study researchers.

In these schemes, farmers apply water using furrow irrigation method and water is diverted from the rivers for 24 hours. Water withdrawal was monitored using float method. The monitoring was repeated three times for one measurement and the average value was used. This monitoring was conducted during the morning and late afternoon hours. Since the float method provides only surface velocity, we used the commonly adopted correction factor of 85% to obtain average canal velocity of each scheme.

To obtain the volume of water withdrawal data collectors measured the wetted depth of the canal and the canal width (a constant value). The canals in this study were of rectangular shape. These values were multiplied with the canal velocity to estimate the water withdrawal amount. To convert daily measurements to volume per day we used the time factor 24 hrs. This is supported by the information from the farmers on the constant and continuous (day and night) water diversion from the river to the canals.

We used descriptive statistic to summarize the measured water diversion from the rivers. These are daily minimum and maximum discharge to show the range of the variation within the observation period, the dry season, standard deviation, and coefficient of variation were also used to quantify the variability during the irrigation period. The mean value is used to compare the differences between the monitored schemes in the sub-basin.

2.3 Spot Discharge Measurement

During Year 1 the Gumara catchment was found to be facing water scarcity challenges as rivers have gone dry during irrigation season (Taye *et al*., 2021). Given that the national river gauging site of Gumara

River is located at its outlet, it cannot capture the spatial variations of streamflow amount at different locations that can occur due to irrigation water withdrawal. Therefore, to better understand the spatial water availability in the catchment we measured the Gumara River and its tributaries from upstream to downstream location at seven locations (spots). Two measurements were conducted during the medium and low flow seasons where irrigation water withdrawal is common.

Spot discharge measurements were done at seven sites along the Gumara River. Current meter (SEBA mini current meter) was used to measure the river velocity below the water surface at a depth of 0.6 times the flow depth. SEBA mini current meter is capable of flow velocity measurement for streams, rivers, and channels with low water level. Since flow velocity varies laterally across the rivers, the cross-section was divided into multiple segments and the flow velocity and flow depth were measured for each segment. We estimated the discharge of each segment by multiplying the flow velocity by the measured flow depth and segment width. The total discharge at each measurement site was estimated as a sum of the discharge of the segments. River discharge variation from the upstream to the downstream of Gumara was then analysed by comparing the discharges of the seven spot measurement sites.

To understand the extent of irrigation sites in the Gumara catchment, a field survey was conducted at a total of 674 locations. In these locations some have individual pumps and others have a group of pumps (up to 40 pumps in 100 meters distance) in one location to divert river water to farmlands. Also, other structures for water abstraction that are used in this catchment from springs and groundwater sources are explored in the survey.

3. Results and Discussion

3.1 Irrigation Water Withdrawal

Depending on the site, the withdrawal of water diverted from rivers ranged from 559 m^3 day^{-1} to 17824 m^3 day^{-1} on average during Year 1 (Table 2). In Year 2 the withdrawal of water diverted from rivers ranged from 1039 m^3 day^{-1} to 16230 m^3 day^{-1} (Table 3). The daily diversion shows variability during the dry season. At most schemes the variability is less than 50%. In Year 1 two schemes from Bahir Dar zuria district show 60% and above coefficient of variation. In Year 2 two schemes in Fogera district show the highest variability. In all cases water diversions were the highest during the start of the irrigation season and they show decreasing trend until the end of the irrigation season.

The amount of water diverted mostly correlates with the size of the irrigated area and the size of the rivers (Figure 2). However, in some schemes high amount of water is diverted to irrigate only small hectares of land (e.g., at location Enferanz W). This indicates how water is not used efficiently in these schemes. In other cases, the reported irrigated area is large while the amount of water diverted is relatively low. This might show inaccurate estimation of irrigated area by the local officials. Water abstraction rates for each scheme can be estimated by dividing the volume of diverted water by the irrigated area. The total annual water abstraction in the sub-basin can be estimated using these water abstraction rates multiplied by the total irrigated area data that is annually monitored by each district's agriculture bureaus.

Table 2. Summarized descriptive statistics for daily measured water diversion from five districts representing the daily average (mean), the maximum (max) and minimum (min) daily diverted water, the standard deviation (Std), and coefficient of variation (CV) during the data collection in Year 1

District name	River	Measured flow statistics ($m^3 day^{-1}$)				
		Mean	Max	Min	Std	CV
Dangila	Abay	13784	19079	11048	886	6%
	Kuashini	13461	18512	8885	2016	15%
	Zuma	10611	24538	1652	3828	36%
Bahir Dar zuria	Enferanz W	17824	81242	4628	11353	64%
	Enferanz S	9166	61435	4918	5502	60%
	Enamay Wuha	2300	3317	1385	434	19%
Mecha	Bered	3500	6253	1771	1353	39%
	Gogu Wuha	2020	4117	1201	526	26%
	Serja	4009	6249	2289	827	21%
Fogera	Barena	559	1157	311	131	23%
	Wureko	9074	12104	5754	973	11%
	Silkena	1928	4009	713	809	42%
Farta	Achi	1674	3307	501	615	37%
	Taybosh	2062	3800	218	893	43%
	Zemeha	1144	2151	326	393	34%

Table 3. Summarized descriptive statistics for daily measured water diversion from seven districts representing the daily average (mean), the maximum (max) and minimum (min) daily diverted water, the standard deviation (Std), and coefficient of variation (CV) during the data collection in Year 2

District Name	River	Measured flow statistics ($m^3 day^{-1}$)				
		Mean	Max	Min	Std	CV
Dangila	Kuashini	16230	27575	11374	2964	18%

District Name	River	Measured flow statistics (m^3 day^{-1})				
		Mean	Max	Min	Std	CV
	Zuma	4467	9076	2510	1504	34%
	Asher	3991	5508	3219	383	10%
	Enamay Wuha	3047	4722	2404	755	25%
Bahirdar Zuriya	Enferanz W	13113	26352	13087	4575	35%
	Enferanz S	8916	17,501	7471	1365	15%
	Bered	4,665	7,824	2728	1331	29%
Mecha	Goguwuha	1,767	2,840	1081	453	26%
	Serja	4,110	6,767	2926	737	18%
	Barena	1,140	6381	667	848	73%
Fogera	Wondegri	1,039	1619	869	190	18%
	Silkena	2,966	14263	308	2673	90%
	Shemamatebiya	1699	2037	1654	99	6%
Dera	Tibik	7340	10434	7933	382	5%
	Shina	11682	13133	10344	727	6%
	Shini 1	2431	4077	1137	603	25%
Libokemkem	Shini 2	1808	3756	369	488	27%
	Gezana	2113	4833	1024	820	39%

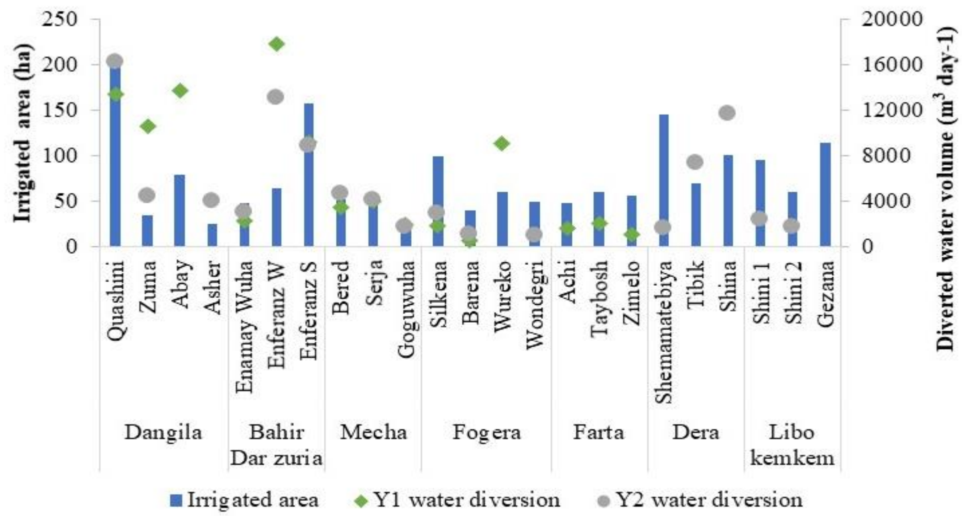

Figure 2. Irrigated area correlation with water withdrawal volume in Year 1 and Year 2 at the irrigation schemes surveyed for this study.

3.2 Spot Discharge Values along Gumara

Based on the spot discharge measurement, there is a decrease in water flow from upstream to downstream along the main Gumara River. For example, the quantity of Gumara discharge at Wanzaye (Figure 3) is 8.3 $m^3 s^{-1}$ during medium flow season and 0.55 $m^3 s^{-1}$ during low flow season. The Gumara river at downstream of Wanzaye (Figure 3) location is 5.6 $m^3 s^{-1}$ during medium flow season and 0.54 m^3/s during low flow season. Within a few kilometres difference between the two locations, the discharge dropped by 2.8 $m^3 s^{-1}$ during medium flow season and 0.01 $m^3 s^{-1}$ during low flow season. This suggested that there is substantial irrigation practice along the Gumara River. This is also evidenced from the irrigation sites' location survey as shown in Figure 4. The area between Wanzaye and the downstream point is crowded with irrigation sites pumping from the river (Figure 4).

At the downstream area, the river has higher amount of water that comes from tributary rivers and back flow of water from the Lake. However, in the middle at different tributary rivers (Sensawuha and Meterey) where irrigation activities are high (Figure 4) and at the upstream of the catchment rivers have low amount of flow (Table 4). These rivers usually experience drying or very low flow during the peak irrigation season (Table 4).

It is therefore important to understand the spatial differences of water availability in the catchment regarding the different activities that occur to devise proper planning of water use. This study demonstrates that such type of flow monitoring is doable and critical for better long-term water management, allocation among different users including upstream-downstream water sharing, and locations that face water scarcity due to high water withdrawal.

Table 4. Measured discharge amount during medium and low flow seasons at the seven spot measurements' locations

No.	Spot locations	Medium flow (m^3 s^{-1})	Low flow (m^3 s^{-1})
1.	Upper Gumara 1	0.06	0.01
2.	Upper Gumara 2	0.35	0.09
3.	Sensawuha	0.91	0.13
4.	Meterey	0.27	0.08
5.	Sebat wodel	0.40	0.03
6.	Wanzaye	8.30	0.55
7.	Downstream of Wanzaye	5.63	0.54

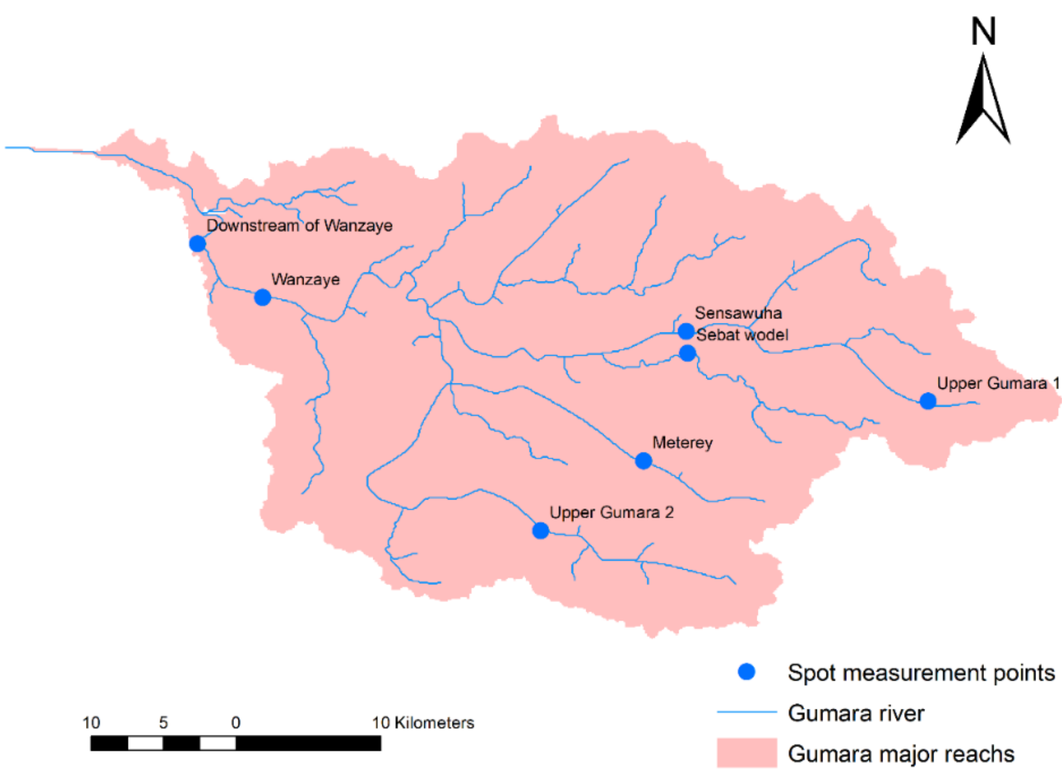

Figure 3. Spot measurement locations in the Gumara catchment

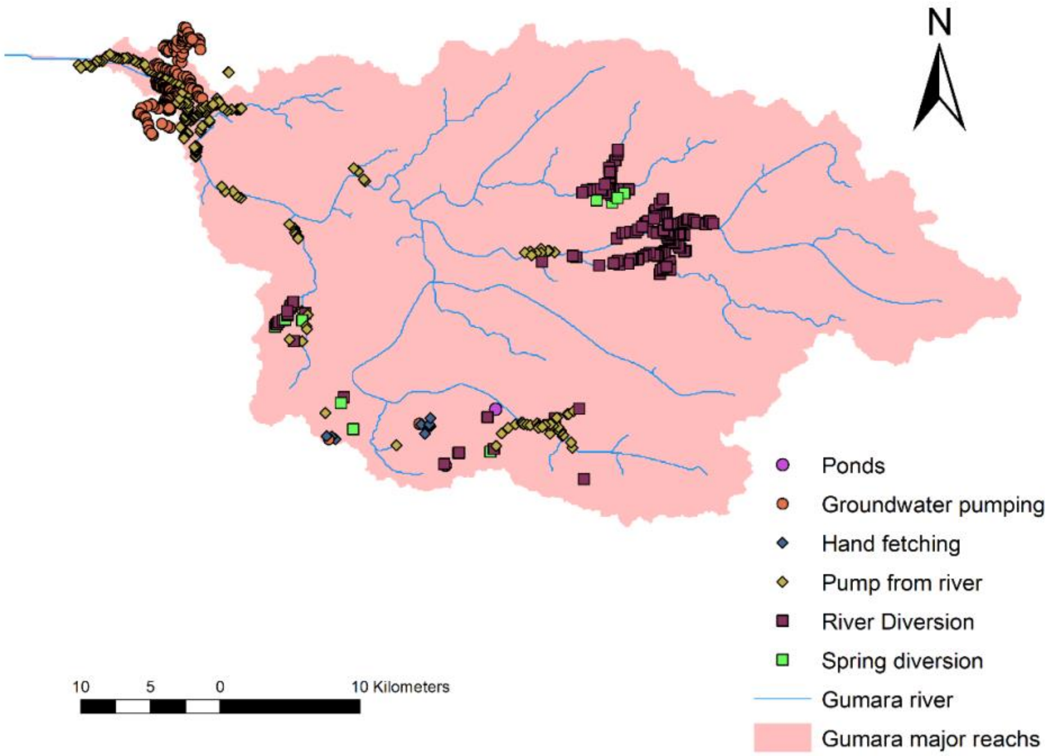

Figure 4. Irrigation sites surveyed in the Gumara catchment

4. Conclusions and Recommendations

Agriculture takes the largest share in the sub-basin's livelihood and irrigation is gaining more attention by farmers. Monitoring water withdrawal used for irrigation and streams amount at different locations will assist in understanding localized water scarcity challenges and finding appropriate solutions. In 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 (Taye *et al.* 2022). Due to uncontrolled abstraction localized water scarcity is happening in different locations, especially in the eastern part of the sub-basin. In some locations water is diverted in high amount while the irrigated area is not as big. Such conditions show water efficiency problems as water is lost without beneficial use can be very high. This is due to the current types of irrigation methods (mostly furrow irrigation) and available irrigation infrastructure as also discussed in Abera *et al (2020).*

The absence of a database that collects information on actual irrigated area and water withdrawal amount can be something that can be improved by the concerned government organizations. This study suggests that irrigation withdrawal monitoring needs to be adopted by district or kebele level water or agriculture offices. This is important given that irrigation is increasing and the impact on the hydrology will increase in the coming years. As water resources become limited efficient use and water allocation can only be supported if proper monitoring can be conducted regularly.

In already water stressed catchments such as the Gumara River, spot discharge measurements are important to understand the localized differences in water scarcity. This study suggests that other researchers to take lesson from this experiment and continue to conduct similar measurements so that knowledge is built in the area about the relationship between irrigation water withdrawal and the river discharge. This is helpful to understand the temporal changes of withdrawal and rivers amount over the years. Additionally, it will be useful to better understand the upstream and downstream linkage in water use.

Researchers are also encouraged to consider such kind of measurements in their research. From such type of monitoring empirical relationships, change detection, upstream and downstream linkage can be observed. Future studies can explore sustaining the monitoring through community-based approaches and in collaboration with relevant local institutions. Learning from previous research activities conducted by the International Water Management Institute can be scaled up at watershed, catchment, and sub-basin scales.

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