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Research Article

Estimation of Current Water Use over the Complex Topography of the Nile Basin Headwaters: The Case of Ghba Subbasin, Ethiopia

Mehari Gebreyohannes Hiben[1,2] **Admasu Gebeyehu Awoke,**[1] **and Abraha Adugna Ashenafi**[3]

[1]*School of Civil and Environmental Engineering, Addis Ababa University, Addis Ababa Institute of Technology (AAiT), Addis Ababa, Ethiopia*
[2]*MG Water Resources Consultancy Firm, Mekelle, Tigray, Ethiopia*
[3]*Ministry of Water and Energy, Addis Ababa, Ethiopia*

Correspondence should be addressed to Mehari Gebreyohannes Hiben; hiben123@gmail.com

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Quantifying the available and useable water is critical work in any water resource study and design project. However, it is challenging to provide a robust and accurate estimation of water use and distribution for better water resource management and planning. This study aims to estimate the water use by different sectors, including water supply and irrigation sectors, by adopting estimated demand and supply water quantity. The current total population of the subbasin has been estimated to be 1.21 million. Thus, in the subbasin, current water use is estimated as follows: domestic and nondomestic water use in the rural area is 3.5 Mm^3/year and 0.174 Mm^3/year, respectively. The domestic water use of the towns is 12.77 Mm^3/year. The industrial water use of the urban areas is 21.2 Mm^3/year, whereas the commercial, public, and institutional water use are 1.87 Mm^3/year. The real loss for all the water supply uses is 7.8 Mm^3/year. Thus, the total current water supply uses are about 47.225 Mm^3/year. From the existing irrigation schemes, about 10,254.8 ha areas are irrigated by both smallholders and different investors, growing vegetables, cereals, and fruit trees. The annual irrigation water requirements of these schemes are computed to be 151.55 Mm^3. Livestock water demand of the subbasin was assessed and estimated based on the population and consumption rates of the species. Currently, the subbasin has a total livestock population of 1,527,835, and the water demand of which is estimated at 5.3 Mm^3 per annum. Hence, the total current water use estimate of the subbasin is 204.1 Mm^3.

1. Introduction

The rapid growth of the population is causing an alarming demand increase in freshwater resources (e.g., lakes, rivers) of the world [1–3]. Continuously people who are living in different states or even within the same boundary are creating conflicts over water that they withdraw from common sources, often and even decades pass by, but such water disputes are not resolved [4, 5]. Water use is often metered in all other sectors except in the agricultural sector. In this paper, we examined a case study of current water use estimates in the Ghba subbasin using geographical information system (GIS) and collected data. Several studies, e.g., [6–8], have applied the same techniques for the estimation of agricultural water use using GIS and collected data.

Before the assessment, the study briefly reviewed FDRE Constitution [9], Water Resources Management Policy [10], Water Resources Management Proclamation [10], Water Resources Management Regulations [10], Nile Basin Initiative Reports [11], Central Statistical Agency Reports forecasted the population of Ethiopia from 2014 to 2017 [12], and another related strategic document of water resource management policy (WRMP) prepared and ratified by the Ministry of Water and Energy. The subject of water allocation planning and its sustainable use is directly addressed in the objective of WRMP of the country, which states: "... to enhance and promote all national efforts towards the efficient, equitable and optimum utilization of the available water resources of the country for significant socioeconomic development on a sustainable basis" [10].

Currently, in the study area, many investors and local farmers are using different sizes of pumps upstream of the river for irrigation purposes. This water abstraction is done without knowing their current water use, which sometimes creates a violent water conflict. Thus, the economic water scarcity in the subbasin is threatening the livelihoods of smallholder farmers, investment activities, and unique biodiversity resources. This situation has made the need for wise water management, which includes demand planning and water allocation plans, more urgent than ever. Therefore, the motto of this manuscript is to initiate and create a platform to assess the current water use with simple and more reliable techniques while dealing with the study and design of any irrigation and water supply projects.

The study presented in this paper is designed mainly for the civil engineers engaged in the study and design of water supply and irrigation projects. Also, it helps policymakers to understand how the water resource system in a specific subbasin/catchment is behaving. Therefore, the main objectives of this study are to estimate the water uses for water supply (domestic, nondomestic, Commercial, Public, and Institutional Water Uses), irrigated agriculture (all water supplied for irrigation farms and horticultural production, as well as water used to irrigate public and private plots), and the livestock water uses including the smallholders and investment enterprises.

2. Materials and Methods

2.1. Description of the Study Ssubbasin. The Ghba subbasin is positioned in northern Ethiopia and covers from 38°38' to 39°48' Eastern longitudes and 13°14' to 14°16' northern latitudes (Figure 1). The total area of the Ghba subbasin is about 5125 km^2 and comprises the Tigray regional state's capital city Mekelle. It forms the headwaters of the Upper Tekeze River basin, one of the major tributaries of the Nile River [13]. The landscape is characterized by highlands and hills in the north and north-eastern and highlands in the central part of the catchment [14]. The central highlands are divided by numerous rivers that flow towards the south-western part of the subbasin and joins the main Tekeze River at Chemey [15]. The altitude varies from 3,300 meter above seas level (m.a.s.l.) at Mugulat Mountains near Adigrat town to 930 m.a.s.l. At the subbasin outlet [16]. The mean elevation of the catchment is 2144 m, with a standard deviation of 361 m indicating that the topography is very rugged [15].

Water demand datasets of water supply, irrigated agriculture, and livestock are required for the estimation of current water use analyses. These numerical analyses directly depend on the quality and length of the time series data [17]. Therefore, sufficient exertion was given to verify the accuracy of the dataset. These datasets and methods are summarized in the following sections, and the overall method of current water use estimation is structured in Figure 2.

2.2. Hydrometeorology and Socioeconomic Data. The national growth and transformation plan- II (GTP-II), national growth and transformation plan- I (GTP-I), One WASH national program (2013–2020), universal access program (UAP), urban water supply design criteria [18], guidelines for drinking-water quality [19], the millennium development goals (2000–2015), and the sustainable development goals (2015 to date and beyond) by the United Nations [20] were reviewed for the current water use assessment and demand projection purposes.

The Ghba subbasin is known for its high socioeconomic development in the Tigray National Regional state [21]. The size of the population in the subbasin is increasing so alarmingly because of emerging new cities and the expansion of industries, livestock, and modern irrigated agriculture [22]. The population water intake is taking a significant share of the water resources that are either from the river, runoff, deep well, and/or shallow well. Therefore, computing their demand under current and future condition is vital to estimate the overall water supply sector water requirements [17].

Generally, there is uncertainty about the actual domestic water use dataset collected from the Woreda and regional stakeholders of the subbasin area [23]. Thus, to reduce the level of data uncertainty, water consumption of the urban and rural settlements was estimated based on per capita water uses recommended by GTP-II [24, 25] and population size and indexed by the water supply coverage rate reported by the region [26]. According to the GTP-II plan, rural settlements in Ethiopia will enjoy 25 litters of per capita domestic water consumption by 2020 [27]. Thus, this minimum threshold value is adopted and factorized with the reported water supply coverage of the areas to estimate the actual domestic water consumption. Similarly, as per the GTP-II, e.g., [27, 28] water supply service level standard, it is required to provide safe water in urban areas in accordance with the category of towns set in line with the population size (Table 1).

During the field assessment, large numbers of industries of all categories were identified in the subbasin. However, data on the actual water consumption rates of all the identified industries still had some uncertainties [29]. To reduce the level of uncertainties, good data values were adopted and factorized with the capacity of the industry, e.g., [24, 30].

The water uses of facilities, such as schools, hospitals, hotels, and small commercial enterprises, and also public service water use centers were assesed. This depends on the extent and development of the institutional and commercial base and varies with the domestic water use [31, 32]. As this water use data could not be available, the values are also estimated as a function of the domestic water use.

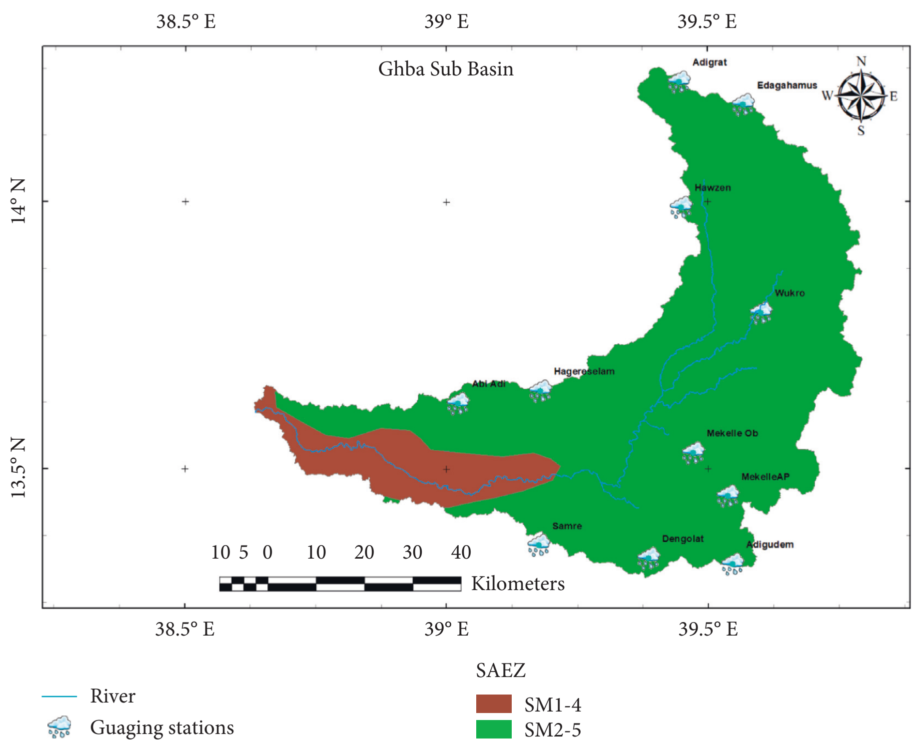

FIGURE 1: Agroecology and meteorology stations of the Ghba subbasin.

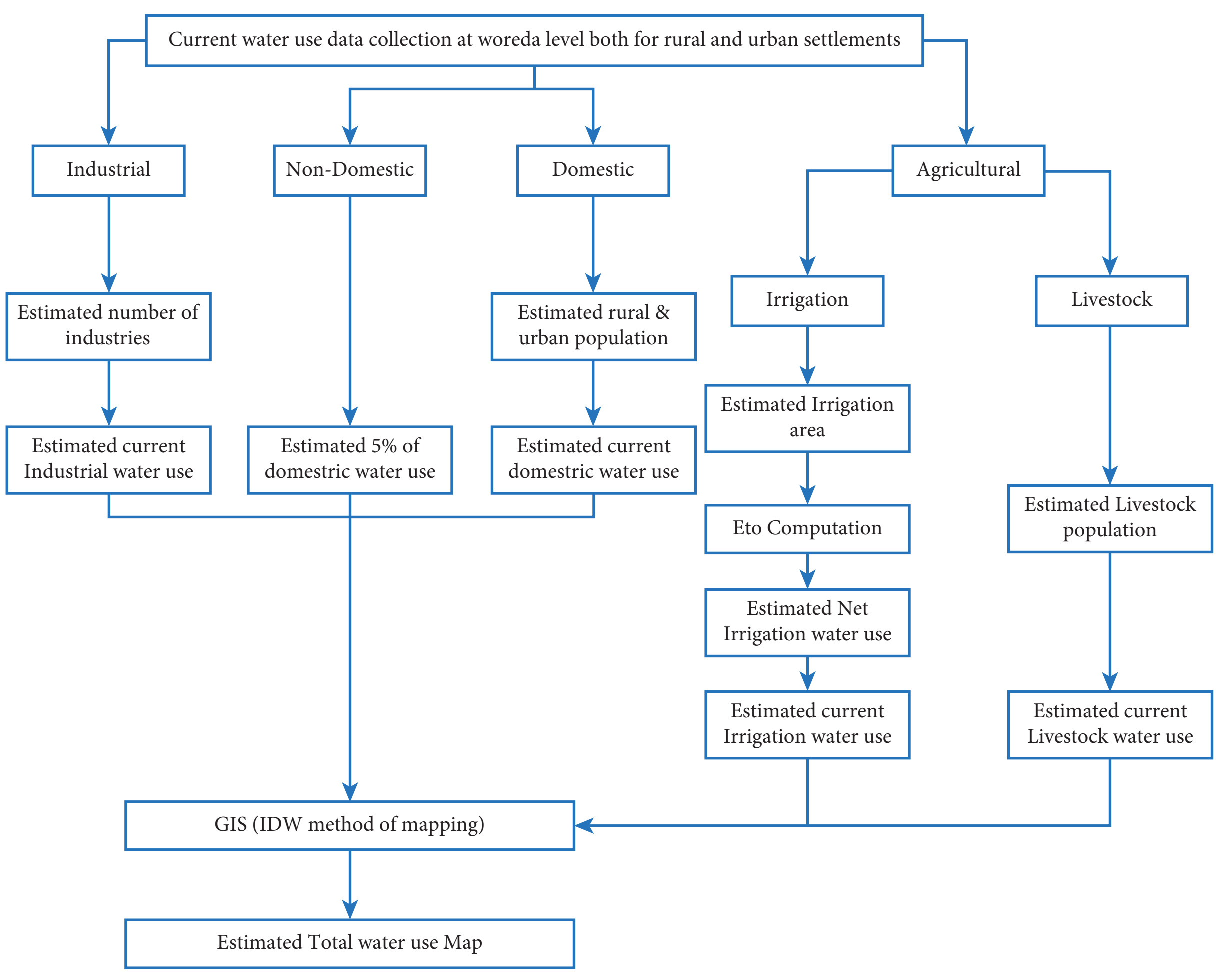

FIGURE 2: Flow chart of total current water use estimation and mapping techniques.

Table 1: Urban categories according to GTP-II.

City level	Population size	Per capita water use target at the end of GTP-II, $l/c/d$
1	>1,000,000	100
2	100,000–1,000,000	80
3	50,000–100,000	60
4	20,000–50,000	50
5	<20,000	40

Source: GTP-II plan, strategic document for water sector development.

Long-term data from selected meteorology stations representing the climatic conditions of identified major agroecology of the Ghba subbasin was collected from the Ethiopian national metrological services agency [33] and compiled to get the long-term annual, monthly average data of rainfall, temperature, wind speed, sunshine hours, and relative humidity. The agricultural water demand assessment of the subbasin has considered major agroecological zone distribution that has a direct influence on the variability of irrigation water utilization and crop water requirements. Out of the identified 32 subagroecological zones of the country [34], two of them are found in this subbasin (Figure 1), and about 15 meteorology stations of different classes are being located in the subbasin, and its periphery used as the climate data source for water requirement analysis after screening 11 stations in the basin were considered for further analyses considering the data quality, length, and agroecology conditions. The two major and subagroecology of the subbasin as reported by MOA [34] are Tepid to cool submoist mid-highlands (SM2), Hot to warm submoist lowlands (SM1), Tepid to cool submoist plains and mountains and plateau (MS2-5), and Hot to warm submoist river gorges (MS1-4), respectively (Figure 1).

Here, the estimation of ETo was the first step to calculate the crop water requirement based on temperature, humidity, wind speed, and sunshine hours of the respective area [35, 36]. The monthly ETo data was used for the computation and establishment of monthly crop evapotranspiration (ETc) [37]. The Penman-Monteith method [38], which is the most common and recommendable method, was used in estimating ET_0 and is adopted in the demand analysis (Table 2). The overall estimation method of irrigation water requirement estimate is characterized in Figure 3.

The monthly water requirements of the recommended crops were then computed after fixing the evapotranspiration of the target area and identifying the crop coefficients of the existing irrigated crops [39, 40]. Appropriate crop coefficient (Kc) values for each growth stage were selected and applied [41, 42]. Accordingly, an overall average of 40% irrigation efficiency was used for all current irrigated areas after averaging the different efficiency used in the Woredas [26].

The annual crop water consumption of surface and other high-tech irrigation schemes operating in the subbasin was assessed by gathering data from respective irrigation users' offices, investors, and our measurement data for the selected projects from 2019 up to 2020. Then, the gross irrigation use and the requirement were estimated based on the computed net irrigation requirements and irrigation efficiency depending on the purpose of the computation [43, 44].

2.3. Agronomy Data. Crop coefficient and length of growing period (LGP) are the required inputs to estimate the irrigation water requirement of proposed crops. To calculate the water requirement of the individual crop, appropriate crop coefficients Kc have been used, which represent the relationship between the reference crop water requirement and evapotranspiration ETo, this being x Kc = ET crop.

Accordingly, the crop coefficients were referred from different research works of literature and adopted with a monthly weighted value of them for each crop and their growth stages.

In the case of crop LGP, the required data were collected from the field for dominant crop varieties and also referred to different agronomy guidelines [45]. In the following Table 3, the crop coefficient and length of the growing period for each of the considered crops are presented. Hence, according to many researchers, e.g., [46–48], the equations recommended by FAO [45] to compute current irrigation requirements are summarized from equation (1) through equation (3) as follows:

where

$$CWR = ETc = ETo * Kc, \tag{1}$$

$$NIWR = CWR * A_{\text{crop},} mm/\text{period}, \tag{2}$$

$$GIWR = \frac{NIWR}{E_p}. \tag{3}$$

ETc = Crop evapotranspiration (mm/day).

ETo = Reference crop evapotranspiration (mm/day).

Kc = Crop coefficient (fraction).

CWR = Crop Water Requirement.

NIWR = Net Irrigation Water Requirement.

GIWR = Gross Irrigation Water Requirement.

E_{p} = Overall Irrigation efficiency, including the conveyance, distribution, and field application efficiencies.

A_{crop} = Area coverage in a season (ha).

2.4. Domestic Water Use Data. Table 4 summarizes the current water supply capacity data for the Ghba subbasin collected from different water utility offices. Mainly the

Table 2: Computed evapotranspiration of different agroecologies of the subbasin.

Station name	Lat°	Long°	Alt. (m)	Mean annual ETo (mm)	SAEZ	MAEZ
Mekelle	13.45	39.53	2,260	1,744	SM2-5	SM2
Adigrat	14.00	39.27	2,470	1,755	SM2-5	SM2
Adigudem	13.16	39.13	2,100	1,796	SM2-5	SM2
E/hamus	14.18	39.56	2,700	1,544	SM2-5	SM2
Hawzen	13.98	39.43	2,255	1,886	SM2-5	SM2
Illala	13.52	39.50	2,000	1,752	SM2-5	SM2
H/Selam	13.65	39.17	2,630	1,573	SM2-5	SM2
AbiAdi	13.62	39.02	1,850	1,987	SM2-5	SM2
Samre	13.13	39.13	1,920	1,867	SM2-5	SM2
Dengolat	13.19	39.21	1,950	1,643	SM2-5	SM2
Wukro	13.79	39.60	1,995	1,749	SM2-5	SM2

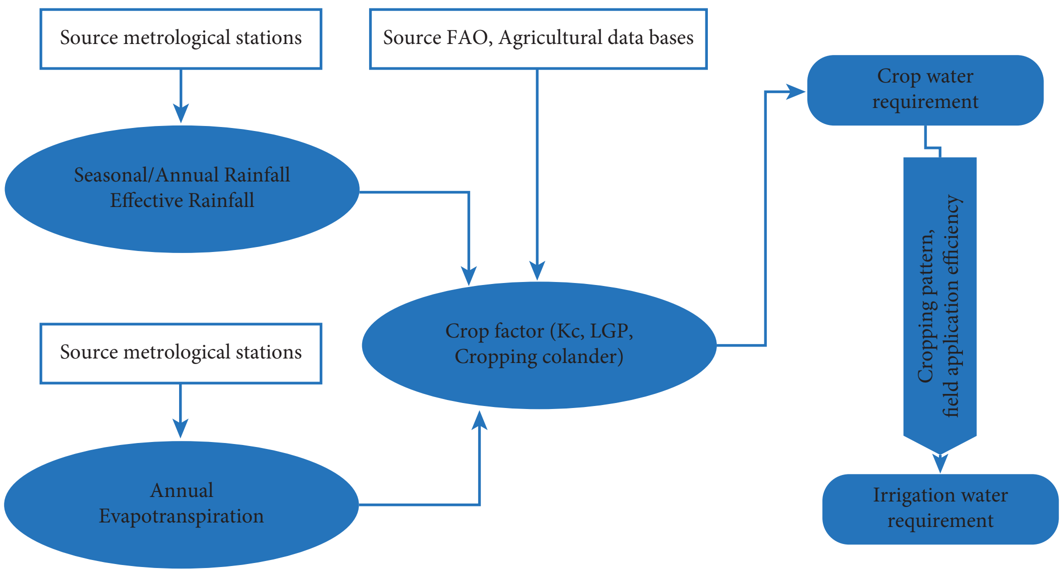

Figure 3: Flowchart showing procedures in the estimation of irrigation water requirement.

Table 3: Crop coefficient and length of the growing period used for CWR computation.

Crop	Kc				LGP, in days				
	Initial	Dev.	Mid	Late	Initial	Dev.	Mid	Late	Total
Cabbage	0.5	0.75	1	0.95	20	30	35	25	110
Onion	0.5	0.75	1.05	0.85	20	35	40	25	120
Pepper	0.35	0.7	1.05	0.9	25	35	40	20	120
Tomato	0.45	0.75	1.15	0.9	20	30	40	20	110
Carrot	0.7	0.85	1.05	0.95	15	30	30	15	90
Kale	0.7	0.7	1	0.95	30	60	60	30	180
Papaya	0.9	1	1.1	0.9	60	80	90	60	290
Potato	0.45	0.75	1.15	0.9	25	30	45	30	130
Sugarcane	0.45	0.85	1.15	0.75	30	60	180	95	365
Beet root	0.45	0.8	1.12	0.95	15	25	30	20	90

Source: FAO irrigation and drainage P 56; MOA, 2018 SSIGL irrigation agronomy guideline.

Table 4: Current water supply capacities of Woreda *s* and towns in the subbasin.

Existing water supply capacity (m^3/month)							
S/N	Zone	Woreda	Supply	Source	Town	Supply	Source
1	Eastern	Atsbi Wenberta	76,361	GW, river	Abi Adi	35,483	GW
2	Central	Degua Temben	89,508	GW, river	Agbe	12,424	GW
3	Southern	Enderta	73,098	GW, river	Hagereselam	28,291	GW
4	Eastern	Ganta Afeshum	53,590	GW, river	Mekelle	760,668	GW, SW
5	Eastern	Hawzen	75,422	GW, river	Quiha	33,420	GW
6	Southern	Hintalo Wejerat	94,885	GW, river	May Makden	10,939	GW
7	Eastern	Kelete Awelallo	53,613	GW, river	Agulai	21,650	GW
8	Central	Kola Temben	72,354	GW, river	Wukro	69,725	GW
9	Eastern	Saesie Tsaedaemba	69,959	GW, river	Hayki Meshal	15,395	GW
10	Southern	Saharti Samre	60,242	GW, river	Atsbi	25,054	GW
11	Central	Tanqua Abergele	45,189	GW, river	Sinkata	24,504	GW
12					Edaga Hamus	26,719	GW
	Total		764,220			1,064,272	

sources are groundwater (GW) followed by surface water (SW).

2.5. Existing Irrigation Area. As summarized in Table 5 data of existing irrigation areas in hectarage (ha) were collected from all stakeholders who are working on the development of irrigation infrastructure in the sun basin.

3. Results and Discussion

Thus, the urban categories in accordance with the population size and proposed service levels collected from the Woredas and the current water supply coverage are mapped in Figure 4. Figure 4 contains two pieces of information; category means according to the policy of the country based on the consumption rates, towns are categorized under categories 1, 2, 3, 4, and 5. Thus, the map tells which city is categorized where. The second information is about the coverage of water supply in the study area and is described in percentages range. Hence, there are different methods of mapping; our choice of mapping was by district level, i.e., mixing of those areas in the range of the expressed percentage.

3.1. Nondomestic and Industrial Water Use Estimate. Thus, as the major industries located in the subbasin have recorded water consumption data, other water uses were also estimated indirectly based on the data from similar industrial water use. Apparently, for planning purposes, a reliable Industrial Water Demand indicator was assessed and found to be more than 100% of Domestic Water Demand in large and medium towns and 20% to 60% of Domestic Water Demand in small towns [49]. This current industrial water use estimate is summarized in Table 6.

These water uses are categorized here as nondomestic and include all water consumption other than domestic in the case of rural areas. The nondomestic water uses for the rural areas were also estimated based on the domestic water use, which is assessed to be 5% [50, 51]. Accordingly, current commercial, public, and institutional water use of both urban and rural areas in the subbasin are summarized in Table 7.

Table 5: Collected data of existing irrigated areas in the subbasin.

Irrigation coverage in each Woreda inscribed by the subbasin				
S/N	Zone name	Woreda name	Area (ha)	Coverage (%)
1	Eastern	Atsbi Wenberta	264.73	0.47
2	Central	Degua Temben	627.60	0.78
3	Southern	Enderta	4,558.61	4.82
4	Eastern	Ganta Afeshum	168.68	1.43
5	Eastern	Hawzen	205.26	1.05
6	Southern	Hintalo Wejirat	215.72	1.33
7	Eastern	Kelete Awelallo	2,660.85	3.06
8	Central	Kola Temben	150.00	0.57
9	Eastern	Saesie Tsaedaemba	698.63	1.55
10	Southern	Saharti Samre	127.91	0.43
11	Central	Tanqua Abergele	576.84	1.22
Total			10,254.82	2.00

The loss of water from the existing water supply schemes is included in the estimation of the total water use. In principle, the magnitude of the loss of water depends on different factors that include age and length of distribution pipe, operating pressure, number of connections, and maintenance services given to the system. As the actual value of loss could not be quantified, often it is reported as a percent of the total demand, and its value varies from 5 to 30% [51].

In the current study, real water loss percentages that varied from 10 to 30% were adopted according to our data measurements, and water utility offices with the size of population and time as proposed by current assessment and previous studies [52, 53] are used for estimation of current water loss. Apparently, real water loss estimated for the rural and urban settlements of the Ghba subbasin is summarized in Table 8.

3.2. Agricultural Water Use Estimate

3.2.1. Irrigation. Maximum effort was made to verify the collected data of irrigable land delineated by GPS in each

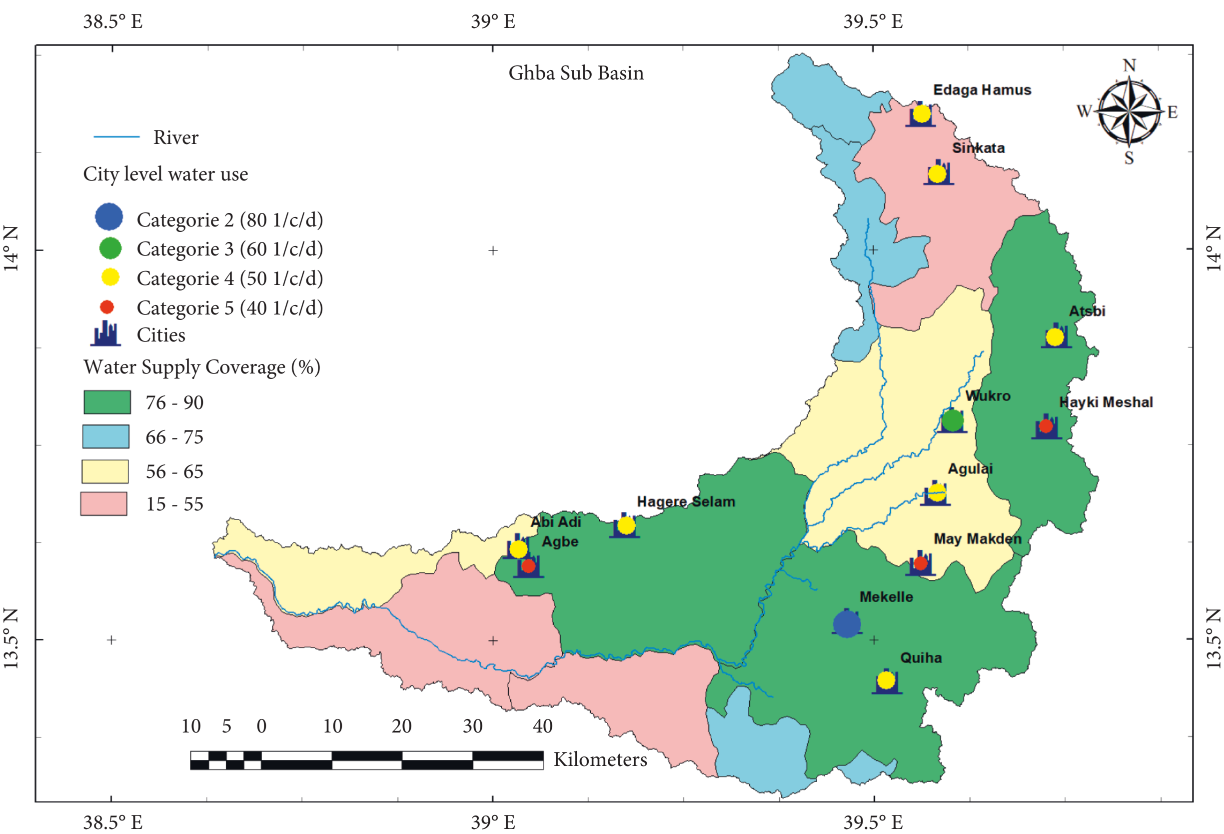

Figure 4: Water supply coverage at Woreda level and urban categories of the subbasin.

Table 6: Current industrial water uses of the urban areas in the subbasin.

	Existing water supply use (m^3/month)			
S/N	Industry	Town	Use	Source
1	Velocity textile	Mekelle	230,668	GW
2	Mekele steel industry	Mekelle	16,383	GW
3	Ma garment	Quha	19,961	GW
4	Mekele industry zone	Mekelle	320,667	GW, SW
5	Quiha Textile	Quha	117,371	GW
6	Semayata marble	Wukro	12,969	GW
7	Sheba lazer	Wukro	26,013	GW
8	Mesfin industrial	Mekelle	43,800	GW
9	Selam steel factory	Mekelle	17,271	GW
10	Wukro car assembly	Wukro	14,565	GW
11	Dera water bottling	Atsbi	16,581	GW
12	A summary of more than 100 small industries	Mekelle	929,600	GW, SW
	Total		1,765,849	

Woreda. Continuous consultation and assessment were made with the Woreda offices and Tigray Water Resource Bureau during the field survey. Thus, the total irrigated area for the production year 2021 was mapped in GIS (Figure 5) from the GPS database and verified via Google Earth and physical measurements, and then estimated at around 10,254.8 ha. From the previous assessments and inventory conducted on the irrigated area size mainly by Tigray Water Resource Bureau (TWRB) in 2015 and 2016, the total irrigated areas were 8,725.98 ha and 9,0170.76 ha, respectively. There has been an increment in the irrigated area since the inventory, but the data from Woredas somehow looked exaggerated as compared to the major finding of this study and also when compared to the then TWRB inventory assuming increment due to additional areas developed, though not able to get the specific/actual additional areas since then.

Common rainfed agriculture in the basin includes Teff, wheat, barley, maize, sorghum, and pulses. However, irrigated agriculture at the household level and agricultural investment have also increased significantly in recent years [15, 54]. During the mapping process, those areas less than or equal to 10 hectares were summed up. Furthermore, the

Table 7: Current commercial, public, and institutional water use of the rural and urban areas of the subbasin.

Existing water supply use (m^3/month)							
S/N	Zone	Woreda	Use	Source	Town	Use	Source
1	Eastern	Atsbi Wenberta	1,891	GW, river	Abi Adi	1,774	GW
2	Central	Degua Temben	3,469	GW, river	Agbe	621	GW
3	Southern	Enderta	2,348	GW, river	Hagereselam	1,415	GW
4	Eastern	Ganta Afeshum	574	GW, river	Mekelle	115,953	GW, SW
5	Eastern	Hawzen	869	GW, river	Quiha	8,538	GW
6	Southern	Hintalo Wejerat	398	GW, river	May Makden	547	GW
7	Eastern	Kelete Awelallo	2,301	GW, river	Agulai	1,082	GW
8	Central	Kola Temben	690	GW, river	Wukro	6,164	GW
9	Eastern	Saesie Tsaedaemba	1,364	GW, river	Hayki Meshal	770	GW
10	Southern	Saharti Samre	228	GW, river	Atsbi	2,082	GW
11	Central	Tanqua Abergele	329	GW, river	Sinkata	1,225	GW
12					Edaga Hamus	1,336	GW
	Total		14,460			141,506	

Table 8: Estimated current real water loss of urban and rural areas in the Ghba subbasin.

Existing water supply lose (m^3/month)							
S/N	Zone	Woreda	Loss	Source	Town	Loss	Source
1	Eastern	Atsbi Wenberta	7,146	GW, river	Abi Adi	53,585	GW
2	Central	Degua Temben	13,113	GW, river	Agbe	5,886	GW
3	Southern	Enderta	8,876	GW, river	Hagereselam	9,933	GW
4	Eastern	Ganta Afeshum	2,170	GW, river	Mekelle	239,457	GW, SW
5	Eastern	Hawzen	3,283	GW, river	Quiha	31,866	GW
6	Southern	Hintalo Wejerat	1,506	GW, river	May makden	4,891	GW
7	Eastern	Kelete Awelallo	8,696	GW, river	Agulai	9,749	GW
8	Central	Kola Temben	2,608	GW, river	Wukro	23,938	GW
9	Eastern	Saesie Tsaedaemba	5,154	GW, river	Hayki meshal	6,687	GW
10	Southern	Saharti Samre	863	GW, river	Atsbi	8,340	GW
11	Central	Tanqua Abergele	1,244	GW, river	Sinkata	8,462	GW
12					Edaga Hamus	191,531	GW
	Total		54,660			594,325	

total number, average, minimum, and maximum size of the subbasin population and the percentage distribution of each Woreda population are also mapped in Figure 5.

The mean daily ETo for all the different AEZs in the study area ranges from 4.08 mm to 5.33 mm. The irrigation water demand was estimated for three separate irrigation cycles; the first-round irrigation starts from October to the end of January, the second round of irrigation from early February to the end of May, and supplemental irrigation from June to the end of September.

The current estimated irrigation water demand is summarized in Table 9. Accordingly, the current annual irrigation water demand is found to be 151.51 $Mm^{3.}$ The demand reaches its peak in December (30.87 Mm^3) and January (31.11 Mm^3), while the lowest demand is in June (1.13 Mm^3), also summarized in Figure 6. Thus, the average water demand per ha is 14,778.44 m^3. In estimating the current gross irrigation water demand, the analysis considered the weighted average irrigation efficiency of the current irrigation system data, which is estimated at 40%. Details of existing water consumption on monthly bases are summarized in Figure 6. And also, Figure 7 summarizes the analytical annual output GIS map of ETo, and both current NIWR and GIWR per hectare, or the duty for irrigation water requirement per hectare spatial distribution of the subbasin computed from monthly ETo and agroecological zoning of the subbasin.

3.2.2. Livestock. The current livestock water demand for the subbasin was computed based on the population and average livestock water intake rate per head per day. As mentioned in the previous section, the number of livestock is available from stakeholders, and the average water intake rate values for each species were adopted from this study [55]. The adopted consumption unit rates are presented in Table 10.

According to the study, the total annual current livestock water requirement of the subbasin is estimated at 5.25 Mm^3. As presented in Table 11, the highest consumption demand goes to the cattle group, which accounts for about 69% of the total livestock demand. The share of annual water requirement for sheep is 11%, donkeys 10%, goats 5%, beehives 3%, and poultry 2%.

3.3. Overall Water Use Estimate. Finally, after estimating each current water use at the Woreda level both for rural and urban areas of different sectors, the total current water use estimate of the subbasin is 204.1 Mm^3 and is summarized in

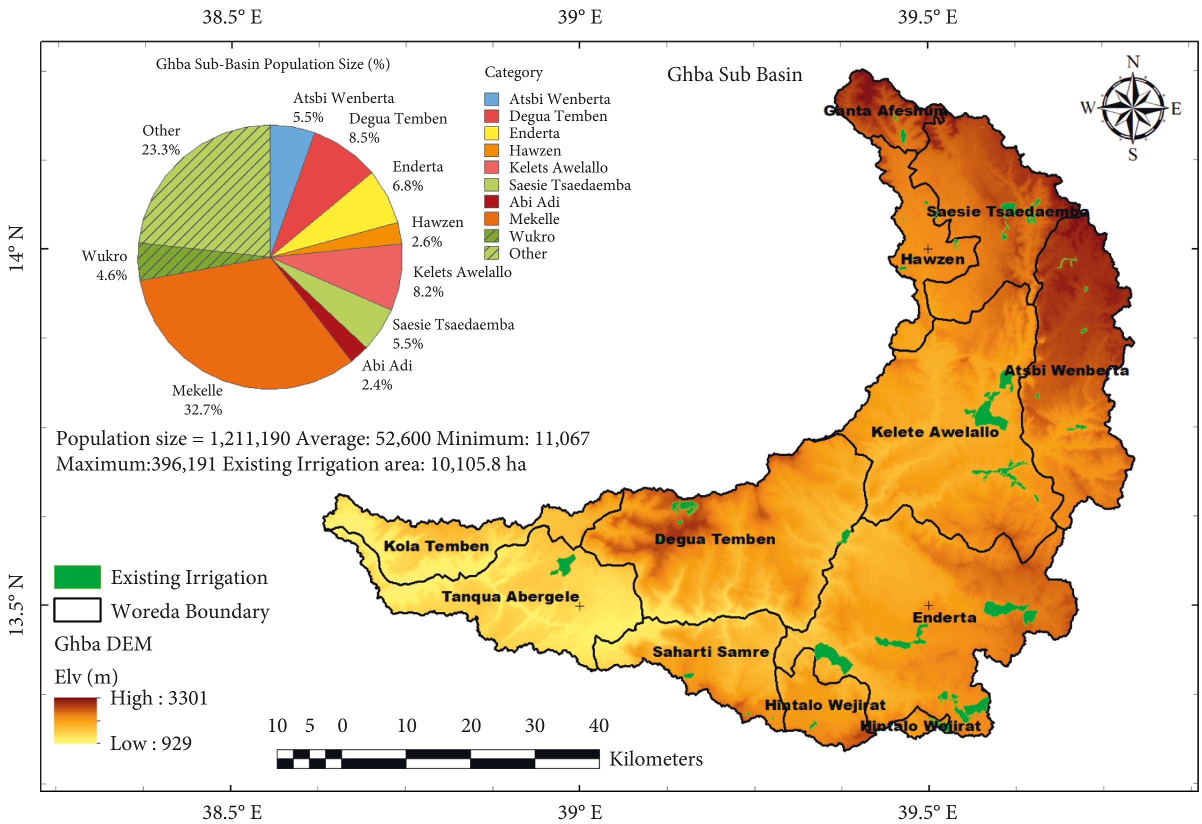

Figure 5: Existing irrigated area and population size distribution in the subbasin at each Woreda.

Table 9: Current estimated irrigation water demand of the subbasin.

Irrigation cycles	Area (ha)	Irrigation water requirement (Mm^3)
First-round irrigation	10,254.80	96.52
Second-round irrigation	7,715.91	47.99
Supplemental Irrigation	2,420.29	7.04
Total	20,391.00	151.55

Table 12, and the estimated current water use GIS map of the subbasin is quantified in raster calculator by IDW method shown in Figure 8. This result shows high stress or water abstraction is in the central part of the subbasin where the capital city of the Regional Government of Tigray is lying, and, of course, almost all industries exist in concentration

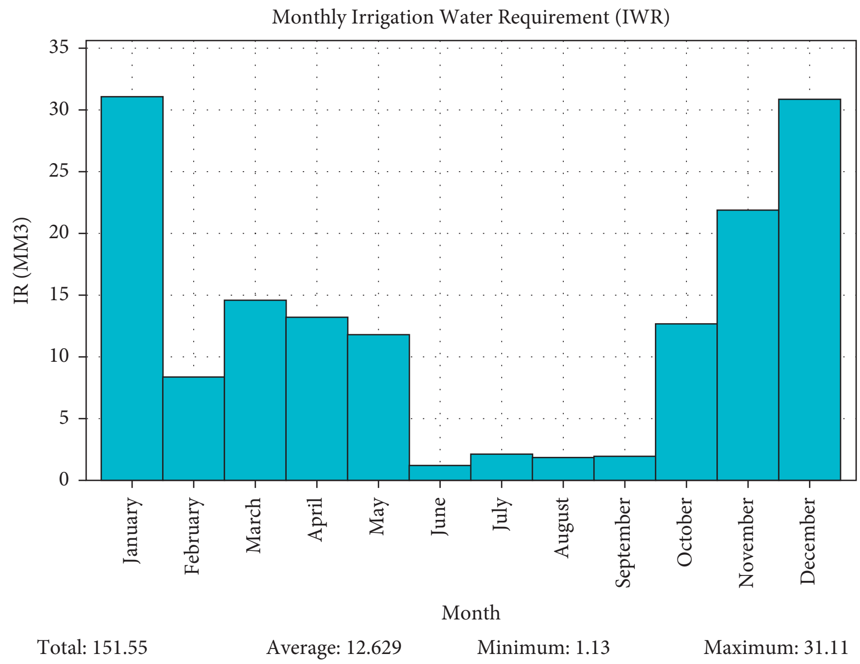

Figure 6: Current monthly irrigation water demand distribution.

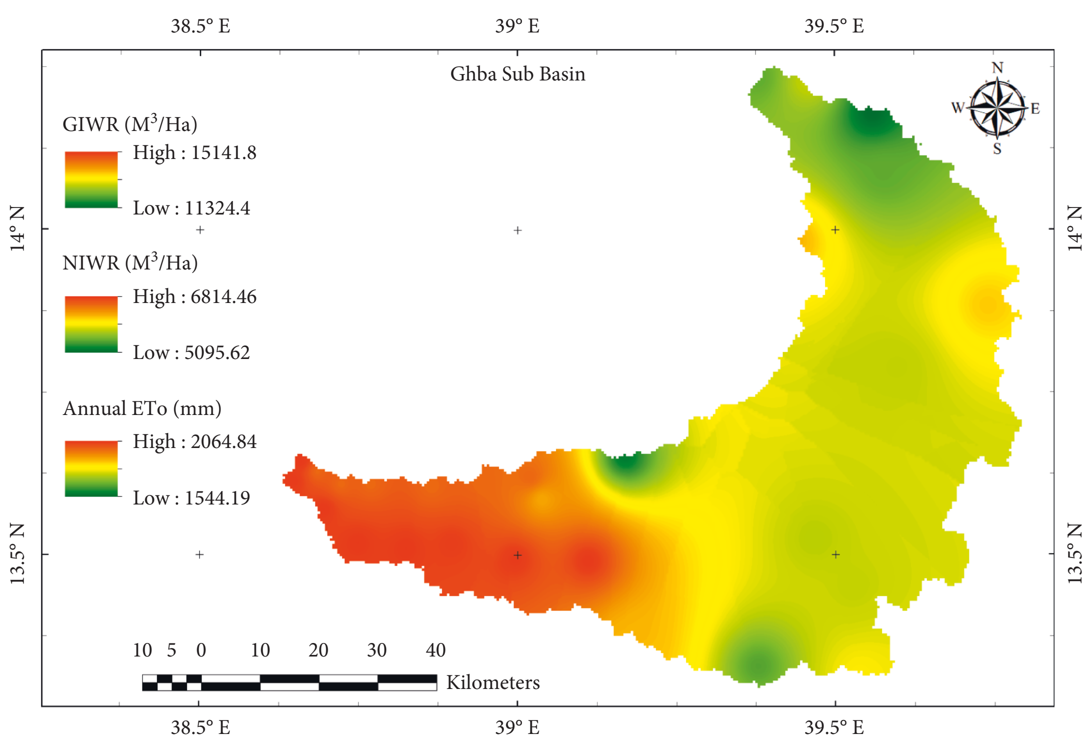

Figure 7: Annual ETo, current NIWR, and current GIWR.

Table 10: Livestock water use rate in liters per head per day (Richard 1995).

SN	Livestock	Average water demand (lit/h/d)	
		Normal weather	Hot weather
1	Cattle	25	30
2	Sheep	5	5
3	Goats	5	5
4	Horses	12	20
5	Mules	12	20
6	Donkeys	12	20
4	Camels	30	20
8	Poultry	0.22	0.4
9	Beehives	11	11

Table 11: Current total livestock population and water demand of the subbasin.

Current annual water use in m^3/year			
S/N	Livestock	Population	Use
1	Beehives	43,265	171,331
2	Poultry	604,665	87,072
3	Sheep	334,304	601,747
4	Cattle	333,269	3,599,303
5	Camel	1,655	17,877
6	Mules	527	3,796
7	Donkey	71,786	516,862
8	Goat	138,087	248,557
9	Horse	277	1,992
	Total		5,248,535

Table 12: Summery of all current water use in the subbasin in Mm^3.

Woreda	Domestic	Nondomestic	Industry	Loss	Irrigation	Livestock	Sum
Atsbi Wenberta	0.75	0.05	—	0.19	3.91	0.69	5.59
Degua Temben	1.17	0.06	—	0.28	9.27	0.95	11.73
Enderta	10.09	1.52	20.35	3.36	67.37	0.50	103.19
Ganta Afeshum	0.75	0.04	—	0.49	2.49	0.14	3.92
Hawzen	0.21	0.01	—	0.04	3.03	0.24	3.53
Hintalo Wejirat	0.10	0.00	—	0.02	3.19	0.09	3.39
Kelete Awelallo	1.96	0.13	0.84	2.87	39.32	1.06	46.19
Kola Temben	0.74	0.04	—	0.67	2.22	0.31	3.98
Saesie Tsaedaemba	0.33	0.02	—	0.06	10.32	0.55	11.28
Saharti Samre	0.05	0.00	—	0.01	1.89	0.16	2.11
Tanqua Abergele	0.08	0.00	—	0.01	8.52	0.56	9.19
Total	16.24	1.87	21.1907	8.00	151.55	5.24	204.10

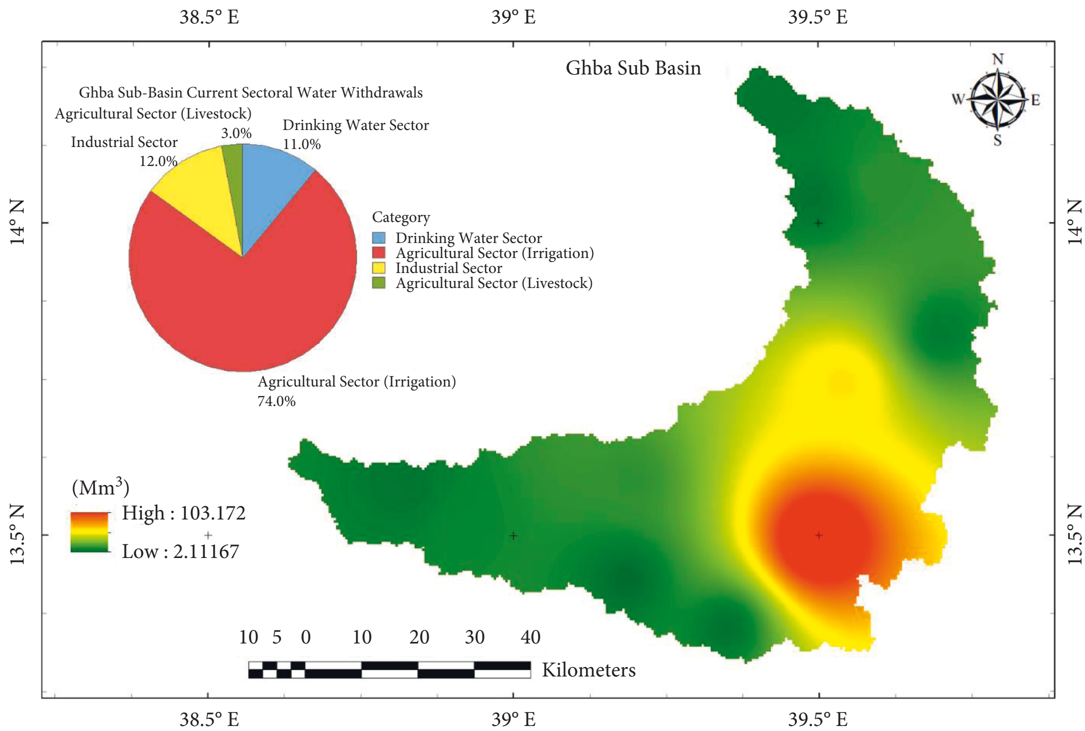

Figure 8: Current total water use/abstraction of the subbasin by sector and spatial.

within this area. Furthermore, the population density in the area is also increasing alarmingly from time to time.

Thus.

4. Conclusion and Recommendation

This study estimates the current use of water both for water supply and agriculture purposes. The estimate shows that the current domestic and nondomestic water use of the rural area of the subbasin is 3.5 Mm^3/year and 0.174 Mm^3/year, respectively. At the same time, the domestic water use of the towns in the Ghba sSubbasin is estimated to be 12.77 Mm^3/year. The industrial water use of the urban areas is estimated to be 21.2 Mm^3/year, whereas the commercial, public, and institutional water use is 1.87 Mm^3/year. The estimated real loss for all the water supply uses is 7.8 Mm^3/year.

The current irrigation water consumption of the above-mentioned groups of irrigation water users was estimated independently, considering their water management efficiency and distribution. The existing irrigated land in 2019/20 was estimated for the first and second rounds under a full irrigation system. The first round, which extends from October to January of the cropping year of 2020/21, has an estimated irrigated land of 10,254.8 ha, while the case of the second-round irrigation period, which extends from February to the end of May, has the area coverage of 7,715.91 ha. In addition, the supplementary irrigation activities, which were mainly experienced in the highland part of the subbasin, had an estimated area coverage of 2,420.29 ha. Based on the estimated irrigated areas of different seasons, the irrigation water consumption for different cropping patterns was estimated using the Penman-Monteith method and empirical formula for ETo, crop water requirement, and irrigation water requirements. Accordingly, the estimated results for smallholders and investors irrigation water consumption in the subbasin is around 151.55 Mm^3 per annum.

Livestock husbandry is the second most important agricultural water user sector in the subbasin. As mentioned earlier, the water used for livestock production simply depends on the current livestock population and rate of consumption for each species. Accordingly, the current (2020/21) total livestock and poultry population of the subbasin is estimated to be about 923, 170, and 604,665, respectively. Accordingly, their corresponding annual water consumption is 5.3 Mm^3.

These methods of current water use estimation are curtail preliminary working input data that have to be incorporated in any study and design of water resource projects. Thus, they help to reduce the level of uncertainty of efficient water use distribution in the study area, violent water conflict, optimum utilization of water resource projects, and so on.

The method of these current water uses estimations considered in this study may not be absolute as validation of these products in different study periods and conditions could result in different estimates. Assessment and interpolation of the data collection and estimation method over complex terrains may also introduce uncertainties and therefore limits the validity of the result. However, considering the current data availability, the result of this study provides a basis for the utilization of water allocation plans for the current and future scenarios over the complex topography of the Ghba subbasin. It will be a useful reference for future related studies of current water use estimation techniques that will help improve water allocation plans.

Data Availability

Data are available at the Ethiopian National Meteorological Services Agency, the Ministry of Water and Energy (Ethiopia), Ethiopian Central Statistical Agency, the Tigray Water Resource Bureau, and THE Tigray Water Utility Offices.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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