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Research article

Impact of irrigation practices on Gilgel Abay, Ribb and Gumara fisheries, Tana Sub-Basin, Ethiopia

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ABSTRACT

In Ethiopia, particularly in Tana Sub-Basin, irrigation development practice is increasing. However, this development ignored the fisheries; no, enough information about its effects. The sub-basin is rich in fisheries, including the 17 *Labeobarbus* species (the only remaining cyprinid species in the world). The fishery is also supporting over 6000 fishers. Hence, this study investigated the impact of irrigation practices on the Gilgel Abay, Ribb, and Gumara fisheries. Methods include fish sampling below and above the weirs, expert interviews, key informant interviews, secondary data, and impact significance matrix methods. The data collection time was from July 2019 to June 2020. The analysis of the data was qualitative and quantitative. The existing irrigation system affects fisheries by blocking upstream spawning migration routes (Gilgel Abay Weir and Ribb Dam, for sure catch below the Gilgel Abay Weir, significantly higher than above the weir, Shannon Index (H'), $P < 0.001$). Besides, according to local sources, after 2007, Gumara and Ribb Rivers became seasonal because of excessive water abstraction for irrigation, resulting in mass fish-killing and the failure of juvenile recruitment to the lake. In one instance, we recorded the deaths of over 930 adults and juveniles on the Gumara and the Ribb Rivers. Succeeding low water volume, even non-fishers collect fish from the pools; and during spawning time, fishers target spawning migratory species at the weirs where the catch is prime is also the other problem. Other threatening elements can also aggravate the impact. Hence, these impacts need to be ameliorated by practicing efficacious water use, catchment treatment, fishery management, fish ladder development, and factor alleviation can be solutions.

1. Introduction

In Ethiopia, irrigation practices are increasing from time to time, and it started with Tana Sub- Basin in 1995 (Eguavoen et al., 2012). The sub-basin hosts about 3.5 million inhabitants (BoFED, 2014), and their livelihoods mainly depend on agriculture. Hence, besides other water uses, they put more pressure on the use of irrigated agriculture. Since they are agriculture dependent besides rain feed agriculture, the use of irrigation is increasing, and as a result, several weirs and dams are running and under construction. However, the area is highly vulnerable to grave environmental degradation because of the unwise use of natural resources and poorly planned development projects, prompted by rapid population growth (Yonas, 2006) and urbanization. Amongst natural resources, the use of irrigation is one of them, and that harms the environment (Dougherty and Hall, 1995; FAO, 2011), particularly in riverine fisheries, i.e., habitat fragmentation in freshwater systems, mainly caused by the irrigation structures (Dynesius and Nilsson, 1994). Large irrigation weirs blocked the upstream spawning migration route of the fish and affected their breeding grounds (Shewit et al., 2017). The pump and diversion systems also divert fish to channels (Baumgartner et al., 2009; Thoms and Cullen, 1998) where injuries and mortalities resulted (Helfrich et al., 2003; Koehn et al., 2003; Koehn et al., 2003; King and O'Connor, 2007).

Aside from its negative impact, irrigation also has tremendous advantages such as increases in agricultural production (Bryan et al., 2013; Alessandra and Tisorn, 2018) and land values (Mequanent and Mingist, 2019); food security, poverty alleviation, rural employment, and improved diets (Lipton et al., 2003; Hussain and Hanjra, 2004). Fish

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production in the irrigation system is also the other advantage (Gregory et al., 2018; Wilder and Phuong, 2002). The best example is the Ribb Reservoir (which is the livelihood of peasants). It is also excellent for combating changing climatic conditions, particularly in Sub-Saharan Africa (Malabo, 2018). However, the benefits of irrigation should not be at the expense of environmental degradation.

Even if the freshwater system is one of the most severely affected on the planet (Sala et al., 2000), its inland fisheries are still a means of livelihood in many parts of the world (Lynch et al., 2016; McCartney et al., 2019). For example, over 6000 fishers rely on fisheries in the Tana Sub-Basin. Therefore, to achieve sustainable development, environmental issues must be integrated into development activities, plans, and policies (Adugna, 2016) and balanced with the health of aquatic resources and ecosystems (Keating, 1994; Mensah, 2002). Thus, the sustainability of agriculture is at the heart of the global 2030 Agenda (United Nations, 2019). Fish move in their environment for food, spawning, sheltering, quality water, etc. (Hortle and So, 2017). However, habitat degradation is a problem (Sparks, 1995; Ward et al., 1999; Bunn and Arthington, 2002) because of irrigation. For instance, water abstraction reduces or stops the main flows (Parineeta, 2012) and perturbations of water variables (Gregory et al., 2018; Siebert and Döll, 2010). So, linked to this, it resulted in the collapse of some fisheries (Arthington et al., 2003; Helfrich et al., 2003). River conditions influence pre-spawning, maturation, spawning cues and behavior, larval and juvenile survival, and later recruitment of migratory fish species (Humphries et al., 1999; Poff et al., 2003; Lytle and Poff, 2004). For example, certain endemic *Labeobarbus* species of Lake Tana wait for a sufficient amount of water to spawn in their breeding grounds; thus, from July to November, they migrate to the flowing rivers of the lake (Nagelkerke and Sibbing, 1996; Palstra et al., 2004; de Graaf et al., 2005; Getahun et al., 2008). Therefore, the spawning route and ground should be safe. If not, as studied by FAO (1997), the irrigation practices themselves will not be sustainable.

The increasing water use sectors in the sub-basin are irrigation, hydropower, domestic water supply, environmental flow, industrial water use, navigation, and tourism developments. However, irrigation has the largest share of water use (de Fraiture et al., 2001). Hence, this highest amount of freshwater use has more problems on the aquatic resources than most other human activities in the world (Lorenzen et al., 2007). Ethiopia is also highly vulnerable to severe environmental degradation because of the unwise use of resources; irrigation is one of the most concerning (Yonas, 2006). Thus, the rapid growth of development activities, irrigated agriculture, should be environmentally friendly. Instead, it should consider fisheries, especially Lake Tana's unique, but threatened 17 *Labeobarbus* species, the only remaining cyprinid species in the world. Hence, to stand these species (sustainable development), we need to integrate the irrigated agricultural water demand and use it with fisheries. The practices of irrigated agriculture (both traditional and advanced irrigation systems) using the Gilgel Abay, Ribb, and Gumara (the main tributaries of Lake Tana) Rivers are the most common. These rivers are also the home of riverine fisheries and the breeding sites of *Labeobarbus* species. Hence, the study aimed to investigate the impact of the irrigation practices on these river fisheries. It also recommends some proposed mitigation measures for the sustainable development of irrigation with fisheries in the rivers.

2. Materials and methods

2.1. The study area

Tana Sub-Basin has an area of 15077 km^2 (Dessie et al., 2014) and is in the northern part of Ethiopia and the northeastern part of the Blue Nile Basin. Lake Tana, the largest lake in Ethiopia, constitutes almost half of the freshwater body of the country (de Graaf et al., 2004) is found in this sub-basin and fed by Gilgel Abay, Ribb, Gumara, and Megech Rivers; together, they contribute over 95% of the total annual inflow (Lamb et al., 2007). The Blue Nile is the only out-flowing river. Of the 28 recorded species, 21 are endemic to the sub- basin (Getahun and Dejen, 2012). The high endemicity is mainly because of the lake's isolation from the lower Blue Nile Basin by 40 m high falls (Tis Isat Falls) (Sibbing et al., 1998). Various studies showed that some of these endemic *Labeobarbus* species migrate upstream for spawning immediately after the rainy season in the inflowing rivers of Lake Tana (Nagelkerke and Sibbing, 1996; Palstra et al., 2004; de Graaf et al., 2005; Getahun et al., 2008; Anteneh et al., 2013; Mequanent et al., 2014). The sub-basin receives a uni-modal rainfall pattern from June to September. The average annual rainfall varies from 816 to 2344 mm, and the smallest was 815 mm, and it is not uniform in the sub-basin (Figure 1).

The mean annual temperature of the area varies from 7.26-23.4 °C, and the highest temperature of the seasons occurred from March to May whereas, the lowest occurred in July to September (ADSWE: LUPESP, 2015). The upper highlands (altitude reaches up to 4109 m) show the lowest mean average temperature, whereas lower ones (1800 m) show the highest mean average temperature.

The sub-basin has high potential (about 13200 ha) for irrigation (Wale et al., 2013), and Lake Tana is the largest freshwater lake in the country (Dessie et al., 2015). Because of this, the government has built several irrigation projects in the sub-basin. For example, Ribb Dam, weirs on Gilgel Abay, and Ribb Rivers (weir I with fish ladders and is 30 km downstream of Ribb Dam) are some irrigation developments at which we have conducted the current study (Figure 2). Ribb Weir II is also a proposed structure between the Ribb Weir I and the Ribb Dam, as seen in Figure 2.

2.2. Sampling

Sampling was from July 2019 to June 2020 twice a month (13th and 14th days). Fish samples were collected below and above the Gilgel Abay Weir and below the Ribb Dam and Ribb Wier I (to see the effect of structures on fish spawning migration route). Below the dam, Ribb Weir I, which is on the same river as seen in Figure 5, because of its fish ladder and alternative waterway, fish could move up to the dam. As, a result species caught below were also found below the dam. Gillnets of stretched mesh size 6,8, 10, and 14 (25 m*1. 5 m) to (100 m*1. 5 m) cm were used. Sampling time was around 7:00 am and retrieved at 10:30. Juvenile sampling was also carried out from December to May using monofilament gillnets of 25*1. 5 (4 cm) by setting up for 2 h in the daytime (8:00 to 10:00) to crosscheck whether spawners crossed the weir and their existence. Data on fish mortality was obtained from local interviews and direct observation and collected those died fish, because of the excessive water used for irrigation (very high-water loss) in the dry season (from October to May). The best example is the Marza River. Fish were identified at the species level using identification keys.

Information (unpublished secondary data) about fishers, motor pumps, and irrigated agriculture areas were collected from corresponding Woreda Agricultural Offices. Likewise, hydrology and meteorological data were also collected from the Ethiopian Ministry of Water and the National Meteorology Agency accordingly.

The discussion was conducted with fishers (27 fishers), irrigation experts (6 experts), natural resource experts (3 experts), and EIA experts (13 experts) from organizations: Region (1 expert), District (6 experts), and Kebele (6 experts), the lowest administrative unit. Similarly, similar discussions were held with locals and irrigation users (at least 19 key informants in each river). Issues related fisheries and irrigation practices (the impact of irrigation on the fisheries and livelihood of fishers') were raised, discussed, and finally listed.

Checklists have been used to capture the relative importance of each impact and evaluation. The Battelle Environment Evaluation Index (EIV) has also been used to aggregate the data collected by scaling checklists.

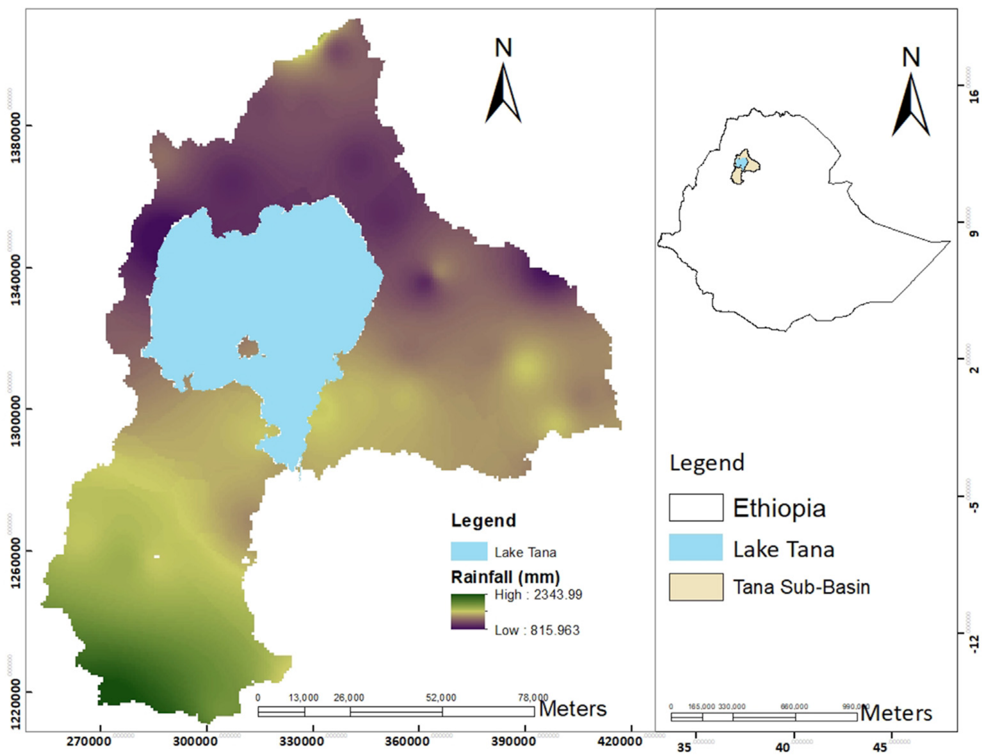

Figure 1. Average rainfall pattern of Tana Sub- Basin.

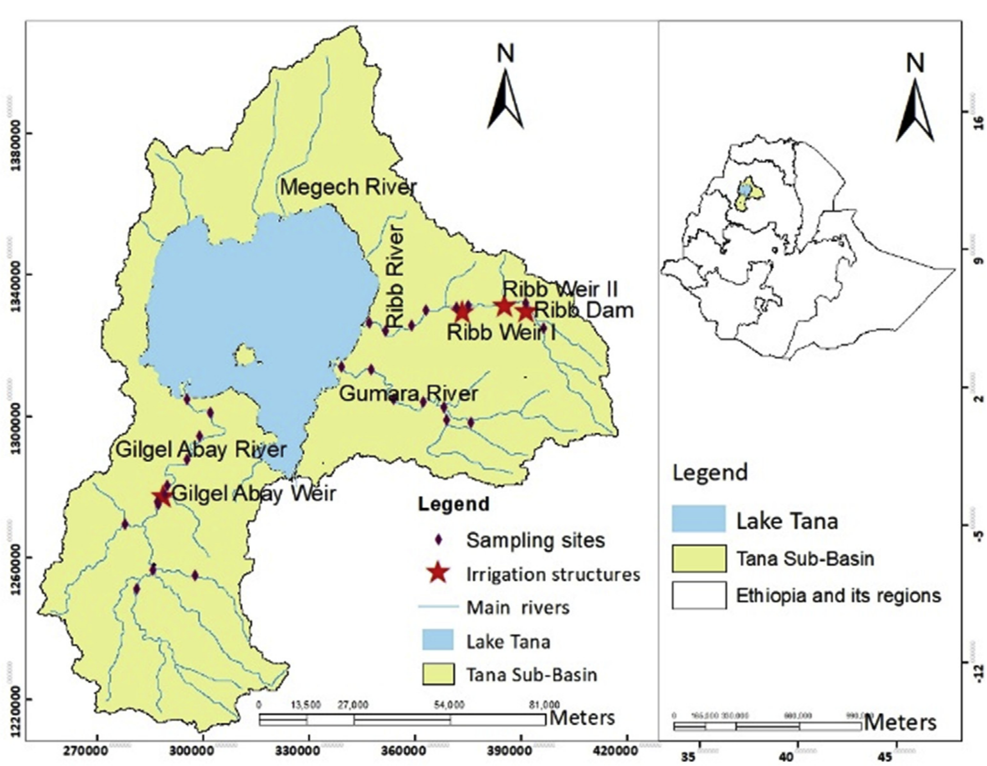

Figure 2. Map of the study area and sampling sites.

$$EIV = \sum_{i=1}^{n} (Vi)Wi$$

where:

EIV = Battelle environmental index value;
Vi = Relative change of the environmental quality by parameters;
Wi = Relative importance or weight or parameter and
n = Total number of environmental parameters.

The magnitude of environmental parameters was given numerical values according to their impact, extent as: very high (+5 or -5), high (+4 or -4), medium (+3 or -3), and low (+2 or -2). The relative importance of environmental parameters (WI) wasn't equally considered in terms of their significance or weight. It varies from country to country. In Ethiopia, the parameters, which can contribute to the growth and transformation plan (like food security, employment, agriculture, and natural resource management) are the most important. Therefore, as shown in Table 4, their values are expressed as very high, high, medium, and low.

Field inspections (direct observations) of irrigation structures, motor pumps, river channels, command areas, and existing irrigation practices were conducted. Existing fishing methods, environmental conditions, and regular fish mortality checks (succeeding low water flow or volume) are also part of the field survey.

2.3. Data analysis

Information about irrigation practices was investigated and analyzed qualitatively and quantitatively. The effect of irrigation structure on spawning migrations of *Labeobarbus* species was investigated and identified by sampling fish species below and above the weirs. was by checking the presence and absence of fish species below and above the Gilgel Abay Weir and below the Ribb Weir I and Ribb Dam. It was also cross-checked and compared before (previous study) and after (the current study) irrigation structure construction. Shannon Index (H') (Krebs, 1989) was used for the analysis of species diversity below and above the weir. So, the species diversity significancy test was analyzed using nonparametric statistics, a Mann-Whitney U test. The magnitude of the developmental activities' impact and testing their significance is the core of the environmental assessment process (Morris and Therivel, 1995). The interaction between various activities and environmental parameters and components were identified using the method EHSC (2016). Identification of significant impact matrix methods and also proposed mitigation measures for the impacts were conducted. The cause of the fish kill was assessed, identified, and analyzed. Qualitative description and narration were used for data analysis. Excel and GIS software were used for data analysis.

3. Results

3.1. Irrigation practices

Using water from the Gilgel Abay, Ribb and Gumara Rivers and their corresponding tributaries, the land area for irrigated agriculture exceeds 16421.08 ha. It is by the means of traditional diversion (N = 2665), weirs (N = 32), and motor pumps (N = 5565) irrigations (Table 1). According to locals, since 2007, the Ribb and Gumara Rivers, in particular, have been used for irrigation until they are dry. Hence, water has always been a limiting factor for irrigation. Because of the traditional irrigation system, the massive wastage of water (Figure 3) also increases the water withdrawal of the rivers, which directly affects the habitat of fish.

Figure 3. Water abstraction using motor pumps in Ribb and its tributary, Marza (mostly rivers dry from March to May).

Table 1. Type of water abstraction methods and command areas (Upper courses of rivers, streams, and some unavailable data were not included) (sources: Corresponding Woreda Agricultural Offices).

River system	Command area (ha)	Structure types and their numbers		
		Motor pumps	Diversions	
			Weir	Traditional
Ribb and its tributaries (at the right)	2265.6+	717	2	-
Ribb (at the left) and Gumara (at the right), and their tributaries	8922	3060	13	1452
Gumara River and its tributaries (at the left)	776.75	901+	-	-
Gilgel Abay River and its tributaries (both sides)	4456.73	887	17	1213
Sum	**16421.08**	**5565**	**32**	**2665**

Low water volume (Figure 4) (aggravated by irrigation) in the dry season (October to May) can't support the fish. According to Mekete et al. (2017), the annual inflows to Lake Tana under an average hydrological condition is about 5.7 × 109 m^3; and he also estimated that this flow will be reduced by about 27% when all planned projects (several proposed irrigation projects on these rivers) are under implementation. Some of the planned or under construction, irrigation projects include Ribb Weir II, dams at Gumara and Gilgel Abay Rivers, and their tributaries (such as a dam on Jema River, the Gilgel Abay tributary).

3.2. Blockage of spawning migration routes

The Ribb Dam and Gilgel Abay Weir completely blocked the upstream spawning migration. Fish were seen attempting to get over the weir without success. Consequently, there was no record or observation of juveniles after the weirs (Table 2). In contrast, Ribb Weir I has a fish ladder (Figure 5) and a temporary replacement waterway that allows fish to move up to the dam.

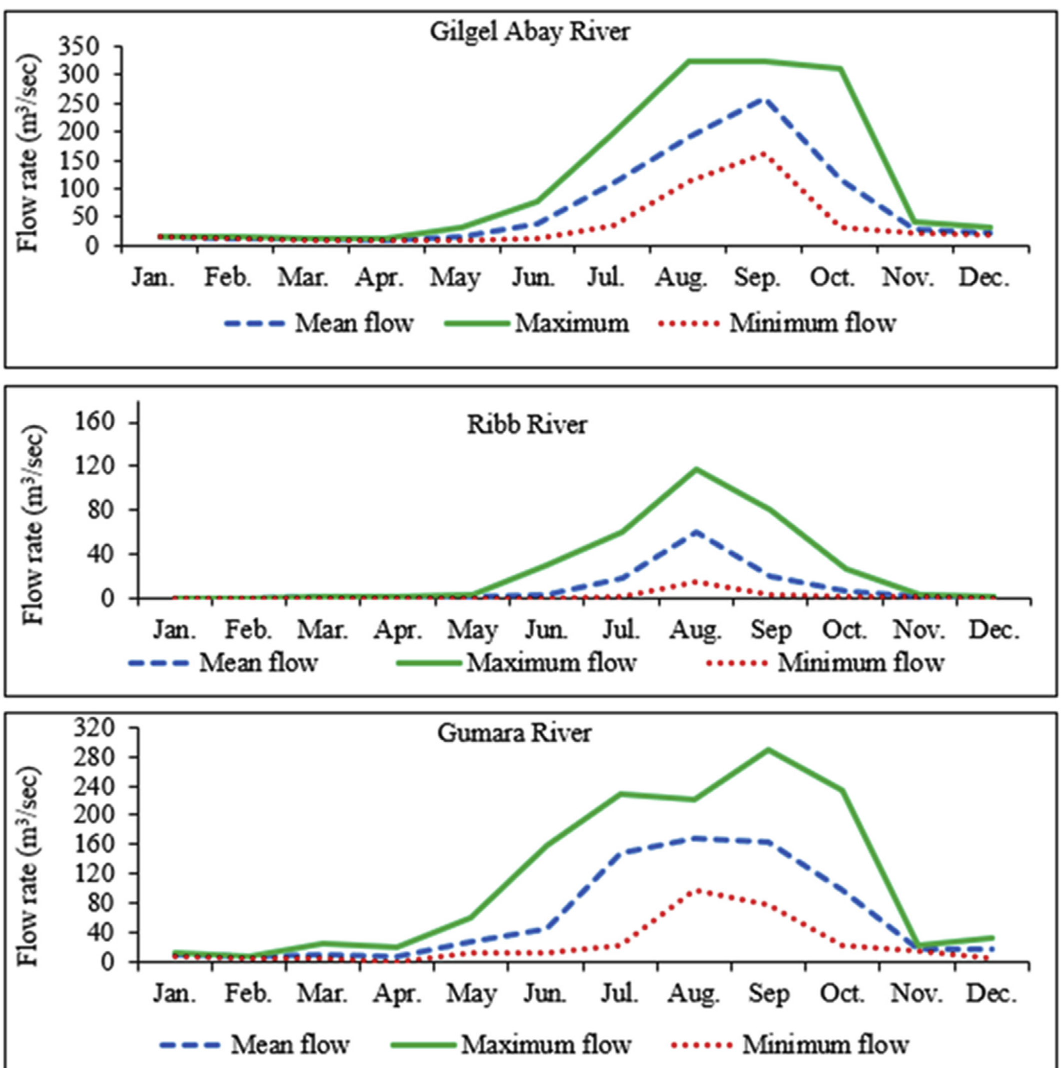

Figure 4. Average water flow rate (mean, maximum and minimum) of Gilgel Abay, Ribb and Gumara Rivers in each month (Source: meteorological data).

Table 2. Presence and absence of migration (spawning) *Labeobarbus* species in Gilgel Abay and Ribb Rivers before and after irrigation structures construction.

Species	Before the structure, construction, some *Labeobarbus* species were making upstream spawning migration in Gilgel Abay and Ribb Rivers (the previous studies)		After structure construction (current study)				
	Mequanent et al. (2014) Gilgel Abay	Getahun et al. (2008) and Anteneh et al. (2013) Ribb	Gilgel Abay River		Ribb River		
			Below the weir	Above the weir	Below the Ribb Weir I	Below the dam	Above the dam
L. intermedius	✓	✓	✓	✓	✓	✓	Fish never moved upstream due to the high dam height (73 m high, without fish ladder) and strong water current coming out of the dam. However, from our observation and information obtained from fishers, there are *Labeobarbus* species which may be isolated due to damming (Cutoff) or riverine origin, and the *C. gariepinus* and *O. niloticus* species.
L. macrophtalmus	✓	✓	✓	x	✓	✓	
L. platydorsus	✓	✓	✓	x	✓	✓	
L. truttiformis	✓	✓	✓	x	✓	✓	
L. tsanensis	✓	✓	✓	x	✓	✓	
L. crassibarbis	✓	x	✓	x	x	x	
L. brevicephalus	✓	✓	✓	x	✓	✓	
L. nedgia	✓	✓	✓	x	✓	✓	
L. Megastoma	x	✓	✓	x	✓	✓	
L. longissimus	✓	x	x	x	x	x	
L. surkis	✓	✓	x	x	x	x	
L. beso	✓	✓	✓	x	x	x	

✓ = present and x = absent.

3.3. Fish mortality

Fish could not get habitats, particularly at Ribb and Gumara Rivers and at their tributaries, because of over-abstraction of water. According to locals' information, because of this, high fish destruction is common. In one instance, it was possible to see and record dead fish along the river course (Figure 6 and Table 3). Amongst the rivers, the Ribb River and its tributaries have the highest death toll, but locals pointed out that except for Gilgel Abay River, mass fish-killing is common. From October to April, the flow rate of rivers decreased, so the death rate increased accordingly. Fishers and non-fishers also collect them easily, and predators too when the water volume is down. Locals also confirmed that pumps and water diversion systems also bring fish into the channels, and mortality rates followed.

Relatively, the volume of the Gilgel Abay River is in a better condition because of few irrigation practices and as studied by Dessie et al. (2015), higher water volume (near to 60% from the inflowing rivers). However, when all other planned irrigation projects are established, the fishery will be at risk. After discussing with key informants and experts, we determined the common impact on the fishery and proposed mitigation measures (Table 4).

3.4. Impact on the livelihoods of Fishers

Over 55 seasonal fishers (at the rivers of Gumara 23, Ribb 17, and Gilgel Abay 15) depend on riverine fishes. However, fishers pointed out that their livelihood failed because fishing after January has become impossible. Therefore, they switched to other means of income during the fishing moratorium. However, Ribb Dam has a positive advantage; i.e., it is a means of living for over 76 fishers organized by the government. But because of the weak management system, illegal fishers (the number is increasing, and they also use forbidden fishing tools), heavily engaged in this reservoir, which resulted in a fight over resource use. The local government should ease this activity.

4. Discussion

According to locals and experts' information and our observation, Ribb and Gumara Rivers are seasonal (drying up mainly from March to May) because of uncontrolled water use for irrigation (Figure 3), the main reason. Analogous to Desta et al. (2019), the locals pointed out that most wetlands have become changed into agricultural lands. Other water demand activities such as new emerging irrigation projects and urbanization are also aggressively increasing. Climate change may also be a threat to this freshwater system. So, related to this and other reasons, the flow rate is decreasing. For example, according to Abebe et al. (2020), Gumara River's mean flows getting decrease from time to time (3.02, 3.19, 1.96, 0.002, and 0.029 m^{3-1} for 1973–1980, 1981–1990, 1991–2000, 2001–2010 and 2011–2018, respectively). Locals and experts also reported that the Ribb and Gumara River systems had already changed because of uncontrolled irrigation water use. In the other rivers, Lehner et al. (2011), Eguavoen et al. (2012), Parineeta (2012), and Matthew et al. (2015), reported similar results. Consistent with the findings of Lucas and Frear (1997), Jacobsen (1998), Pardo et al. (1998), and Bunn and Arthington (2002), it is a threat to the Lake Tana biodiversity (since these rivers are the main tributaries of the lake). It may also exacerbate the extinction of certain endangered *Labeobarbus* species. Thus, poorly irrigated agricultural practices and the structures themselves are the bottlenecks to Lake Tana fisheries. Quiros (1989) and Mallen-Cooper (1996) reported a similar result.

Before the weirs were built, the *Labeobarbus* species had reached the upper reaches of the Gumara and the Ribb (Getahun et al., 2008; Anteneh et al., 2013) and the Gilgel Abay Rivers and their tributaries (Mequanent et al., 2014) for spawning (Table 2). But now, because of the effect of the structure of irrigation, this spawning migration has collapsed. For example, at the Gilgel Abay River, below the weir, the Shannon diversity Index was more significant ($P < 0.001$) than the above (Table 5), and too is the case in Ribb Dam. Fishers and locals have witnessed this, and so

Figure 5. Fish ladder at Ribb Weir, on Ribb River.

have our observations. G Shewit et al. (2017) reported similar results for Gelda and Sini Rivers.

de Graaf et al. (2004) reported that the juveniles of *Labeobarbus* species showed a sharp reduction (>90%), and he also pointed out that the cause was recruitment overfishing. However, according to locals, experts, and our observations, zero recruitment because of habitat degradation (resulting from the overuse of water for irrigation) can be the reason. For instance, we observed the mass killing of juveniles and riverain fishes at Ribb and Gumara Rivers and their tributaries (Figure 6). But before this event, juvenile *Labeobarbus* species used to remain in pools of rivers until the following rainy season (Anteneh et al., 2013a). Within a few sampling times, it was also possible to record over 930 dead adult fish and juveniles (Table 3). The death rate depends on water extraction pressure and river dryness, the highest death recorded in

Figure 6. Observed dead fish at Marza River, end of March 2020.

Table 3. Some recorded dead fish during a few sampling times (March to April 2020). Mass fish-killing is usual along the rivers except for the Gilgel Abay River and deep pools.

Rivers (Sites)	Died fish			Time of death
	Species	Amount (Number)		
Marza (Ribb tributary)	*L. intermedius*	159	+ Numbers of died Juvenile (almost all) was observed. *Labeobarbus* Juveniles were waiting for rainy season to recruit to the lake.	March to April 2020
	L. nedgia	73		
	C. gariepinus	78		
Ribb and Arogew Ribb	*C. gariepinus*	157		End of March 2020
	O. niloticus	271		
Gumara	*L. intermedius*	113		April 2020
	C. gariepinus	79		
Gilgel Abay	-	No record, but were very exposed for predators due to reduced water volume.		

April. So, total fish mortality comes from habitat loss (the whole water abstraction). Helfrich et al. (2003) agreed on this. According to our field observations and confirmation from locals, sand mining is also another problem for juveniles. Because it directly damages the fish during the excavation and their habitat.

Locals and experts also noted the degradation of water sources, biodiversity, and landscapes (displacing former habitats) because of this irrigation practice. In different water bodies, Sophie et al. (2005), David et al. (2000), Dougherty and Hall (1995), Zalewski (2000, 2015), and Richter et al. (1996) reported similar results. Fertilizer and chemical use following irrigation is another problem for the aquatic environment. The river flow reduction (farmers complain at the discussion) is increasing, which climate change can aggravate (Shaka, 2008; Eguavoen et al., 2012), increased evaporation in the irrigated area (Kay, 1996).

4.1. Other threatening and aggravating factors

Practice of illegal fishing activities: Legal and illegal fishers use devastating fishing tools like monofilaments, Seeds of Birbirra tree (*Milletia ferruginea*), fencing, and small mesh (4 cm) even though prohibited by federal and regional (Amhara Region) government fisheries policies (Proclamation No. 315/2003 and 92/2003), leading to the death of many fish. The use of toxic chemicals (such as Malathion) in certain areas of the two rivers and in more areas of the Gilgel Abay River is also a problem. However, today, the local people of the Ribb and Gumara Rivers oppose the use of these chemicals because they think they are affecting their animals. Fishing at the spawning time and grounds is also a major issue. For example, below the Gilgel Abay Weir (Figure 7) where the fish are attempting to move up the stream for spawning (without success), the fishers catch up to 15kg/head/day. This may exacerbate its impact and the decline of the threatened *Labeobarbus* species.

Before introducing water-demanding projects, rainfall variability controlling the water level of the sub-basin (Kebede et al., 2006), now anthropogenic activities like irrigation activities, Cherechera Weir, and the Tana-Beles hydropower are also the controlling factors. In agreement with Tadesse et al. (2009), it is also vulnerable to climate change and showing a decrease from time to time. The change affects runoff and water availability (Shaka, 2008), and locals also agreed on this. There are also high-water demanding activities such as domestic, municipal, transportation, and industrial purposes. Cumulative effects on fisheries like the studies of Mequanent and Mingist (2019) and Contant and Wiggins (1993) may result.

4.2. Mitigation measures

Besides proposing mitigation measures discussed in Table 4, detailed analysis of the environment and social impact, proper irrigation management (Sophie et al., 2005) and the use of environmentally friendly

Table 4. Identified significant impact matrix and proposed mitigation measures.

Observed activities	Potential impact	Significance level	Proposed mitigation measures
a) Irrigation structures	a) Block fish spawning migration	High	1. Construction of the fish ladder
b) Poor irrigation management (water overuse)	b) Wastage of water and leaving a dry or very small amount in the rivers	Very high	1. Efficient water use 2. Upstream watershed management 3. Cultivate drought-tolerant plants
c) Agrochemicals and insecticides utilization	c) Pollution of the environments	High	1. Use recommended Agrochemicals 2. Biological control of insects
d) All fish harvesting and killing	d) Collect all fish when the water level is getting very low and using chemicals	Very high	1. Legal fishing 2. Aquaculture development 3. Leave enough water volume for fish
e) Enhanced sand mining	e) Habitat destruction and mechanical damage	High	1. Approved and recommended mining site, amount, and time
f) No fishing in all season	f) Low or no income of peasants	High	1. Provide alternative means of livelihoods
g) Wetlands conversion to crop production	g) Converting existing land use type into other forms	High	1. Land use identification and implementation
h) Disturbed wildlife	h) Impact on flora and fauna	High	1. Conservation of habitats
i) Dead organism observation	i) Taken out and mechanically damaged by the motor pump, and also due to lack of water in the habitat	High	1. Placing mesh, track rush which will prevent the entrance of organisms to the pump site at least 3–7m radius 2. Releasing enough water to sport organisms 3. Efficient water use
j) Illegal fishing activities (such as fishing at spawning time and site, and use of forbidden fishing tools) observation	j) Total fish mortality	Very high	1. Proper fisheries management

Note: Different researchers have also proposed similar mitigation measures parallel to this table (Table 4). For example, the construction of fish ladders (Larinier, 2002; Gebler, 1998; Travade et al., 1998), prudent water uses habits (FDRE, 2000), and aquaculture development Hortle and So, 2017; McCartney et al., 2019).

Table 5. Presence of species, catch, species richness, and Shannon diversity index below and above the weir of Gilgel Abay River.

No.	Characters	Fish species		*P*-value
		Below the weir	Above the weir	
1	Spawning migratory fish species	Present	Absent	-
2	Catch	1513	20	-
3	Species richness	14	2	-
4	Shannon Index (H′)	1.95	0.65	0.0001

Figure 7. *Labeobarbus* species trying to jump over the Gilgel Abay Weir (a) and at the same time fishers targeting fish below the weir (b) (September 2019).

technologies, fish production in the reservoir and river rehabilitation (Dudgeon, 2005; Nunn and Cowx, 2012) can lessen the impact. Implementation of Environmental Impact Assessment (EIA) of the projects, ameliorating threatening factors of the fisheries and the area; avoiding illegal fishing activities, implementing and improving the fisheries' proclamation (FDRE, 2003; ANRS, 2007), and environmental health policies can mitigate the impact. Detailed studies on the impact of climate change and the establishment of adaptation mechanisms are also necessary.

5. Conclusions

Existing irrigation practices in the Gilgel Abay, Ribb and Gumara rivers have affected the fisheries of these rivers. Because the irrigation structure completely blocked the upstream migration route for spawning (Gilgel Abay Weir and Ribb Dam), and due to too much water use for irrigation, no water in the fishery habitat, which can't support life, kill off life. This excessive water use, particularly at Ribb and Gumara Rivers, resulted in mass fish killing and the failure of juveniles' recruitment. It also affected the livelihoods of fishers. Threatening and aggravating factors such as illegal fishing practices, cumulative impact, and climate change can also worsen the impact. So, the collapse of fisheries in this system is inevitable. Thus, the existing irrigation practice is a threat to the endemic fish species. Hence, implementing mitigation measures can reduce the impact. Such mitigation measures include fish ladder construction, careful water use practices, detailed analysis of the environment, soil and water conservation of the catchment, proper irrigation management, river rehabilitation and buffering, adaptation of climate change impact, and balanced water use mechanisms.

Declarations

Author contribution statement

Dagnew Mequanent, Minwyelet Mingist, Abebe Getahun, Wassie Anteneh: conceived and designed the experiments; performed the experiments; analyzed and interpreted the data; contributed reagents, materials, analysis tools, or data; and wrote the paper.

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Data availability statement

The data that has been used is confidential.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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