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RESEACH ARTICLE

ASSESSMENT OF PHYSICOCHEMICAL PROPERTIES AND FISHERIES ACTIVITIES IN KOGA RESERVOIR, HEAD OF BLUE NILE RIVER BASIN, ETHIOPIA

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ABSTRACT: Reservoirs are potential freshwater bodies that have a significant impact on the development of Ethiopia's fishing industry. This study aimed to assess the potential yield of fish and the current status of fishing activities in Koga Reservoir. Fishermen’s cooperative management team members were selected purposefully to assess the reservoir fisheries activities. Four sampling sites were selected in the reservoir for *in-situ* measurements of physicochemical properties. Primary data was obtained through semi-structured questionnaires, and group discussion. Empirical models were employed to estimate the reservoir fisheries potential. One-way ANOVA and correlation were used for reservoir water quality data analysis. The result indicated that the analysis of physicochemical and nutrients showed non-significant differences among sampling sites except for TDS ($P<0.005$). The mean fisheries potential of the reservoir was estimated to 104.85 tons/year while capture fisheries has been declining due to overexploitation and over abstraction of the reservoir water. More than 60 fishermen benefited from the reservoir capture fisheries. According to the cage farm investor response, the productivity of cage culture was attractive in the reservoir, but it was not sustainable due to management and environmental limitations. This study indicated that the water quality of the reservoir was found within an acceptable range for fish and irrigation, however, depletion of dissolved oxygen and turbidity were critical problems in the reservoir cage culture farm. An urgent management action is needed to sustain the reservoir fisheries based on the capacity of the reservoirs’ potential by restricting the number of fishermen and fishing effort and focusing on stock enhancement.

Key words/phrases: Cage culture, Fisheries, Physicochemical, Reservoir water quality.

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INTRODUCTION

Food insecurity is one of the most bottlenecks in Ethiopia due to the increment in population growth, which leads to increased demand in food consumption. Therefore, exploring alternative methods of food production technologies is vital to boost food productivity in the country. Globally, the fishing sector has a great contribution to a country's economy through the provision of employment, food, and sources of income. However, although Ethiopia is endowed with huge aquatic resources, fishing practices are still at their infancy due to sociocultural, technological, management policies, economic, political and ecological factors and problems (Assefa Mitike, 2014; Mathewos Temesgen and Abebe Getahun, 2016; Agumassie Tesfahun, 2018). For example, some of the main potential fisheries development limitations in the country are lack of scientific information, absence of monitoring and controlling systems, poor organization of fishermen and lack of access to fishing technologies, inefficient market systems, and environmental degradation of the water bodies (Gashaw Tesfaye and Wolff, 2014).

Ethiopia has several constructed, under construction and planned massive irrigation and hydropower reservoirs which have great role in fish production and contribute significantly to the livelihoods of communities living along their vicinity (FAO, 2003; Tsegay Teame *et al*., 2016). The water quality of most reservoirs is suitable for fisheries production and has moderate physicochemical properties. For example, Tekeze, Denbi, and Geray reservoirs have a moderate water quality for fish production (Brehan Mohammed *et al*., 2016; Askale G/Michael and Tegegn Fentahun, 2019).

Empirical models are more applicable methods to estimate the fish production potential of any water body using morphological parameters of rivers, reservoirs, and lakes like distance, depth, volume and areas (Marshall, 1984, Crul, 1992; Van der Knapp, 1994). In Ethiopia, according to the preliminary empirical model studies, the potential fish yield of lentic and lotic ecosystems were estimated at 73,100 and 21,400 tons per year, respectively. It gives a total country fisheries potential estimated at 94,500 tons per year (Gashaw Tesfaye and Wolff, 2014).

FAO (2009) reported that in Ethiopia, fish production has been enhanced through the stocking of newly constructed reservoirs with fingerlings collected from different fish hatchery sites in the country. Besides the natural capture fisheries, cage and pen culture are the recent adopted fish farming types in the natural and artificial water bodies. According to White

(2017), the success of cage culture is determined by the water body in which the cages are placed, as well as the environmental impacts on that water body, water quality, and possibly human activities. In Ethiopia, some studies reported that cage culture was a successful type of fish farming method in Bishoftu Lakes (Ashagrie Gibtan *et al.*, 2008; Tewodros Abate and Abebe Getahun, 2017). Currently, there is an initiation to start commercial cage farms at Koga irrigation reservoir and Gibe III hydropower dam by foreign investors. Koga Reservoir is one of the man-made reservoirs constructed from Koga river, which is one of the tributary rivers of Gilgel Abay (head of Blue Nile) at Mecha woreda in Amhara region. It was constructed for irrigation purposes, but now it serves as the main source of capture fisheries, and it is the first reservoir where commercial cage culture has been established in the country. There are no detailed studies on the limnological and fisheries conditions in Koga Reservoir. So, the current study was initiated to investigate the physicochemical properties for water quality and status of capture and cage culture activities in Koga Reservoir.

MATERIALS AND METHODS

Study site description

Gilgel Abay River is the head water of the Blue Nile River. It is one of the four major tributary rivers of Lake Tana. Koga irrigation reservoir is located within Gilgel Abay River Basin in Mecha woreda of Amhara national regional state (Fig. 1). The reservoir is located near Merawi town, which is situated 35 km south of Bahir Dar town. It is located in Dukima kebele at the confluence of two small rivers (Gibiz and Burka) with the Koga River. Koga River is 64 km long before its confluence with the Gilgel Abay River. The total area of the watershed is about 28,000 hectares. The reservoir is located at a latitude of 11° 10′N to 11° 25′ N, and a longitude of 37° 02′ E to 37° 17′E. The reservoir area coverage is estimated at 20 km^2 or 2,000 ha. The area’s average annual precipitation, minimum and maximum temperatures, are 1,431 mm, 12°C, and 28°C, respectively (Ministry of Water Resources, 2006).

Sample site selection and sampling techniques

The study was conducted between May and July 2020. Before the implementation of the actual survey, exploratory field observation was undertaken at the reservoir and the cage farm. A cross-sectional research design was applied to collect survey data and necessary water quality parameters. Four main sampling sites in the reservoir (outlet, left side, right side, and pelagic zone) were selected purposefully for measuring water quality. Water sampling in the reservoir was carried out only one time. For assessing the reservoir capture fisheries, five fishermen cooperative leaders were purposefully selected. Cage farm manager was selected purposefully to assess the status of cage culture farming practice in the reservoir.

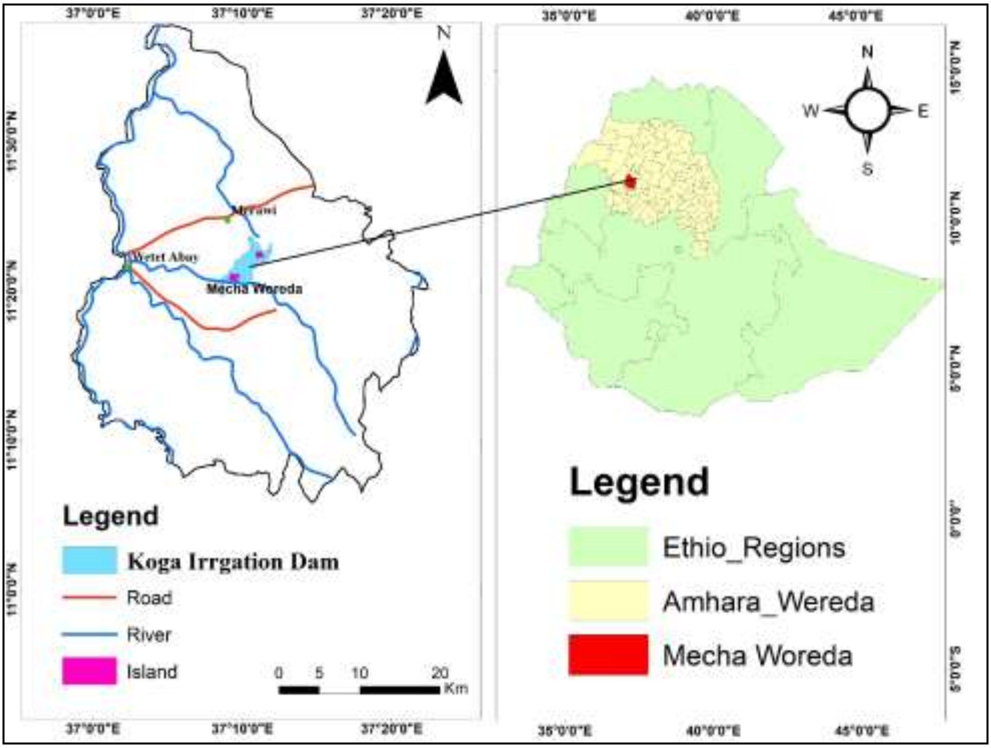

Fig. 1. Map of Koga Reservoir and its catchments.

Physicochemical properties of water in the Koga Reservoir

From each sampling site, triplicate water samples were taken using water sample bottles and transported to the laboratory of University of Gondar for nutrient analysis (Fig. 2). All instruments were calibrated using standard calibration solutions. Physicochemical properties (temperature, pH, conductivity, total dissolved solids (TDS ppm), and dissolved oxygen (DO mg/l)) were measured *in situ* using a portable multi-parameter instrument (Bante 900P). Nutrients (phosphate, nitrate, ammonia, ammonium, nitrite, and sulfate) in the reservoir water were analyzed using a photometer model 7100 using different Palin tests which followed APHA procedure.

Fig. 2. *In-situ* measurement of physicochemical properties and water sampling for nutrient analysis in Koga Reservoir.

Assessment of capture and cage culture fisheries practices in the Koga Reservoir

Data on reservoir fishing practices were collected using semi-structured questionnaires. The interview and discussion were focusing on reservoir fisheries opportunities, challenges, overall fishing activities like fishing effort, type of fish gear, and socio-economic condition of fishermen. Additionally, secondary data on reservoir fisheries resource management, production status, and related issues were collected from the Office of Livestock and Fisheries of Mecha woreda. Data on challenges and opportunities of cage culture was collected using interview with the cage culture farm manager at the farm site.

Methods of data analysis

One-way ANOVA was applied for analysis of the mean variation of physicochemical parameters among sampling sites in the reservoir using statistical software SPSS version 22. The reservoir potential yield was estimated using simple empirical models (1–4). Most used empirical models are area-based and morpho-edaphic index (MEI) as shown in the following formulas:

Model 1: $\ln(Yt) = 3.57+0.76\ln(A_0)$ (Marshall, 1984) (1)

Model 2: $Yield = 14.3136.MEI^{0.4681}$ where MEI is the morpho-edaphic index,

$$MEI = \frac{\text{Conductivity (us/cm)}}{\text{Mean depth in m}} = \frac{148.408}{10} = 14.84 \quad (2)$$

Model 3: $Yt = 8.32\ A_0^{0.920}$ ($R^2 = 0.93$) (Crul, 1992) (3)

Model 4: According to the study of Asian reservoirs, medium-size reservoirs have an estimated mean yield which is 80 Kg/ha/year (Van der Knapp, 1994). (4)

In addition to these models, according to FAO (2003), the total fish production potential of medium size reservoirs can be estimated as 80 kg/ha/year with an average yield per unit area of 5.32 t km^2.

RESULTS

Physicochemical properties

In-situ measurements of some physicochemical parameters such as Temperature, DO, pH, conductivity, Turbidity showed no significant differences among the four sampling sites at Koga Reservoir except for TDS ($p<0.005$). The study confirmed the presence of high turbidity (88.50 FTU) during the study period. The presence of a high amount of suspended materials and dissolved chemicals that arise from the reservoir's upper catchment and are directly loaded into the reservoir could be the cause of high turbidity. The mean amount of dissolved oxygen was also very small (5.64 mg/l), which might due to less biomass of primary producers and high turbidity (Table 1). The mean value of pH was 7.6, indicating the presence of dissolved alkaline minerals. Water conductivity of the reservoir was found in the range between 132 and 156 µS/cm with a mean value of 148 µS/cm, which is safe to use the reservoir water for irrigation, livestock, and fish.

Table 1. Physicochemical characteristics of Koga Reservoir (Mean ± S.E).

Site	Mean & SE	Cond. (µscm^{-1})	TDS (ppt.)	Temp	pH	DO	Turbidity (FTU)
Outlet side	Mean	132.633	64.833	23.400	7.500	5.8667	63.000
	Std. Error	5.67	2.75	0.208	0.058	0.233	11.930
Right side	Mean	156.467	78.367	21.733	7.633	6.4033	93.333
	Std. Error	5.887	2.467	0.689	0.033	1.055	4.4096
Left side	Mean	154.13	76.70	24.56	7.70	5.047	93.33
	Std. Error	2.105	0.818	0.536	.057	0.287	10.138
Pelagic	Mean	150.40	75.30	24.33	7.60	5.24	104.33
	Std. Error	2.57	1.24	0.3756	0.10	0.085	2.33
Overall mean	Mean	148.408	73.800	23.508	7.609	5.6383	88.500
	Std. Error	3.39	1.807	0.394	0.034	0.289	5.81
	P-value	0.019	0.005	0.130	0.178	0.364	0.360

Nutrient analysis of water of Koga Reservoir

The water nutrient analysis of Koga Reservoir showed a medium concentration, in particular, the concentration of nitrate and sulfate were higher as shown in Table 2. All nutrients were not significantly different among sampling sites and this might be due to the presence of high flooding, which causes easy mixing of the entire water of the reservoir. The relationship of water quality parameters showed both positive and negative correlation as shown in Table 3.

Table 2. Nutrient analysis of water quality of Koga Reservoir (Mean ± SE), measurement concentration unit in mg/l.

Sample site	SO_4 Mean ± S.E	PO_4 Mean ± S.E	NO_2 Mean ± S.E	NH_4 Mean ± S.E	NH_3 Mean ± S.E	NO_3 Mean ± S.E
Outlet	97.0 ± 5.0	2.70 ± 0.300	1.27 ± 0.025	0.675 ± 0.57	.635 ± 0.54	3.53 ± 0.53
Left side	103.0 ± 77	1.685 ± 1.22	0.59 ± 0.41	0.430 ± 0.12	0.405 ± 0.12	3.98 ± 0.47
Pelagic	94.50 ± 90.5	1.125 ± 1.07	0.547 ± 0.44	0.505 ± 0.24	0.470 ± 0.23	2.75 ± 1.99
Right side	46.50 ± 34.5	1.30 ± 1.00	0.567 ± 0.42	0.57 ± 0.18	0.535 ± 0.17	2.31 ± 1.12
Mean	85.25 ± 24.5	1.70 ± 0.43	0.744 ± 0.18	0.55 ± 0.13	0.51 ± 0.12	3.14 ± 0 .52
P-value	0.906	0.683	0.52	0.956	0.955	0.764

Table 3. Correlation of physicochemical parameters in Koga Reservoir.

	SO_4^2	PO_4^{3-}	NO_{2-}	NH_{4+}	NH_3	NO_{3-}	Cond.	TDS	Temp	pH	DO	Turb
SO_4	X											
PO_4	0.3928	X										
NO_2	0.3086	0.9585	X									
NH_4	-0.228	0.659	0.818	X								
NH_3	-0.225	0.6727	0.8255	0.9997	X							
NO_3	0.816	0.5866	0.377	-0.2177	-0.2014	X						
Cond.	-0.446	-0.884	-0.965	-0.7682	-0.7704	-0.36	X					
TDS	-0.454	-0.9057	-0.9731	-0.759	-0.7628	-0.39	0.999	X				
Temp	0.934	0.0418	-0.049	-0.530	-0.532	0.68	-0.1187	-0.121	X			
pH	-0.104	-0.651	-0.840	-0.912	-0.906	0.093	0.894	0.876	0.179	X		
DO	-0.851	0.1223	0.237	0.689	0.6911	-0.636	-0.080	-0.076	-0.979	-0.37	X	
Turb	-0.18	-0.974	-0.967	-0.79	-0.804	-0.401	0.868	0.886	0.179	0.74	-0.4	X

The status of fish production and fishing practice at Koga Reservoir

Koga Reservoir fishery practice has been established since 2003 EC (2011/12 GC). According to the response of a woreda fishery expert, more than 13,500 Nile tilapia fingerlings were stocked in collaboration with the Regional Livestock and Fishery Agency and Bahir Dar Fisheries and Other Aquatic Life Research Centre. According to the response from the fishery expert and group discussions with fishermen, the current reservoir total fish production showed a declining trend for the last three consecutive production years (2010–2012 E.C.) (Fig. 3). There are three important commercial fish species found in the Koga Reservoir. The dominant species was Nile tilapia (*Oreochromis niloticus*), followed by catfish (*Clarias gariepinus*), while *Labeobarbus* was only found infrequently. Almost, 2/3 of the total catch composition was attributed to Nile tilapia. The daily catch per individual was estimated at 3.5–7 kg. The price was also fluctuating seasonally, between ETB 30–50 per kilogram. In particular, after Covid-19, the price has declined from ETB 40/kg to 15/kg due to a misunderstanding by consumers that fish might transfer the virus. Based on the different empirical models used, the estimated potential yield of Koga Reservoir was 104.85 tons/year (Table 4).

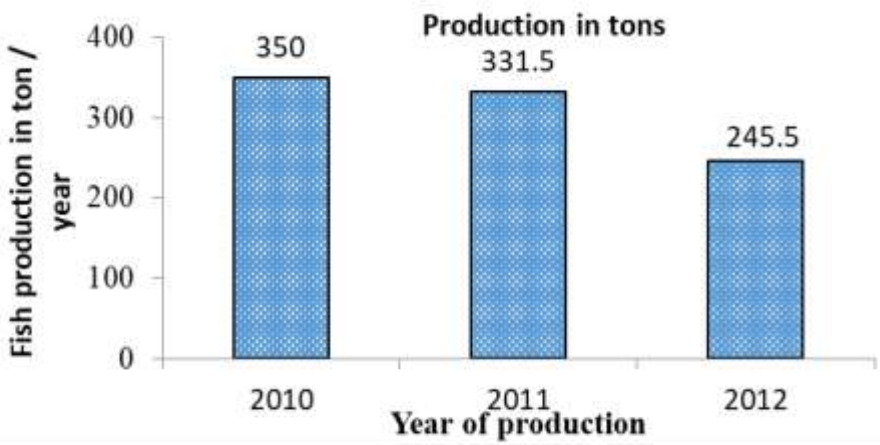

Fig. 3. Status of total fish production for three consecutive years (Source: Mecha woreda fishery report).

Table 4. Annual fish production potential of Koga Reservoir using empirical models.

No	Formula	Potential yield in tons/yr	Sources
1	Ln (Yt) =3.57 + 0.76ln (A_0)	76.67	Marshall, 1984
2	Y = 14.3136.$MEI^{0.4681}$ Where MEI = 14.84	50.59	
3	Yt=8.32A00.92	131	Crul, 1992
4	Mean yield for medium size reservoirs	160	Van der Knapp, 1994
5	5.32 t (A_0)	106	FAO, 2003
	Mean annual yield (t/y)	104.85	

Where Yt: total yield in tons/year; Y: yield in kg/ha/year; A_0: area in km^2; MEI: Morpho-Edaphic-Index, calculated as the ratio of conductivity (uS/cm) over mean depth in meter

Addis Fana fishermen's cooperative is the only cooperative established around Koga Reservoir. During the establishment of the cooperative, more than 60 members were involved. Recently, most members have left the cooperative due to declining fish production and other personal cases. Now, Addis Fana fishermen's cooperative has only 30 male and one female active members. In addition to this cooperative, sometimes some individuals and illegal fishermen also operate in the reservoir fishery.

The current status of commercial cage culture in the Koga Reservoir

Commercial cage culture was established by a foreign investor ASA-Ethiopia Company at Koga Reservoir around 2015 GC. According to the farm manager, the project has three specific sites, such as the indoor hatchery site, the outdoor breeding concert pond, and cage culture at Koga Reservoir. The indoor site is the main hatchery centre for egg incubation and fry production, whereas outdoor concrete ponds are used to harvest fertilized eggs by rearing matured male and female fishes. For a total of 12 concrete ponds constructed for breeding purposes, fertilized eggs were collected once per month from each of the three concrete ponds. The proportion of stocked female and male fishes per pond were 300 females and 100 males or 200 females and 70 males.

According to the response from the farm manager, more than 50 permanent and 60 temporary workers were employed during the active period of the project. Currently, the cage culture farm has shifted to Gibe III Reservoir due to environmental and management problems, and now only few active employees were working in the hatchery site. More than 100 small and large cages were installed at Koga Reservoir during the active period of the project. The size of the cage varied from 25 to 100 m^2. According to the response of the cage farm manager in Koga Reservoir, the total number of stocking fingerlings into each cage was estimated at 30,000 to 40,000, but the survival rate was low. The overall culture system is more intensive and expensive, particularly the hatchery system which needed power for its circulation system.

DISCUSSION

Physicochemical properties of Koga Reservoir

The high concentration of suspended particles which reduces light penetration needed for photosynthesis and oxygen production may be one of the causes of less dissolved oxygen in the Koga Reservoir. According to a previous study conducted by Eriksson (2012), the reservoir had 100 NTU, which is higher than the current study (88.5 FTU). The presence of high turbidity may also have a potential impact on fish feeding and some biological activities of fish. The pH value recorded in this study (7.3–7.4) was higher than in the previous study conducted by Eriksson (2012) in Koga

Reservoir. In addition to sampling season, the study period difference could be the main cause of the change in the pH of the reservoir water, which is related to upstream agricultural activities and an increased high sediment load from year to year.

The reservoir water is acceptable for use of drinking, irrigation, fish, and livestock (WHO, 2011). In agreement with this study, the physicochemical properties of the Geray Reservoir were within the range of the desirable limit for aquatic biodiversity (Brehan Mohammed *et al*., 2016). In contrast to this finding, the recent study conducted by Askale G/Michael and Tegegn Fentahun (2019) reported low levels of temperature, pH, conductivity, TDS, and turbidity of Denbi Reservoir at Bench Maji zone which were 25.14°C, 8.25, 48.94 µS/cm, 24.16 mg/l, and 24.54 NTU, respectively. The difference might be due to the differences in biotopes and sources of pollutants that arise from the reservoir catchment. Another study conducted by Haftom Zebib and Tsegay Teame (2017) reported the low concentration of DO (4.77–4.85 mg/l) and high values of pH, temperature, EC, and TDS of Korrir and Laelay Wukro dams in Tigray region (Tadesse Dejenie *et al*., 2008) and attributed the difference to higher ambient temperature and the presence of alkaline conditions. Moreover, another similar study conducted by Assefa Tessema *et al*. (2014) on the physicochemical water quality of Bira dam found non-significant difference among sampling sites and the water quality to be in the range for all types of water uses. This study revealed that sulfate was found in a wide range of concentrations, ranging from 46 to 103 mg/l. Moreover, nitrate was also found in a high concentration (3.14 mg/l). The cause of the high concentration of these nutrients is not clear as there is no industrial effluent into the river system (Ministry of Water Resources, 2004). Other reservoirs such as Denbi in the Bench Mazi zone of southern Ethiopia had lower nutrient concentrations as reported by Askale G/Michael and Tegegn Fentahun (2019) of nitrate (0.07 mg/l) and sulfate (0.15 mg/l).

The status of fish production and fishing practice at Koga Reservoir

This study revealed that Koga Reservoir has some potential for fisheries production (104.85 tons/year), but the productivity of the reservoir fisheries has declined due to poor fisheries management. In contrast to this study, the potential annual fish yield of Tekeze Reservoir was 1,065.63 tons/year which was estimated using the same types of empirical models (Tsegay Teame *et al*., 2016). The difference might be due to differences in agroecology and difference in size of reservoirs.

The cause of the decline of Koga Reservoir fish productivity might be due to over exploitation, increased use of illegal fishing gears that threaten resource sustainability, increased illegal fishermen and damage of numerous juvenile fish when the diversion wires opened in October for irrigation purpose. According to the fishermen, while the diversion site has built-in mesh wire, thousands of dead juveniles were observed at the diverted irrigation canal. In line with this finding, in some tributary rivers of Lake Tana, more than 40% of downstream migratory juvenile fishes have been damaged by irrigation diversion weirs (Gizachew Teshome, 2014).

Cage culture practice and challenges in Koga Reservoir

While cage culture fish production is attractive, it is not profitable in Ethiopian context due to the high cost of complete feed and the local market doesn't have a return as compared to the production cost. Additionally, the low dissolved oxygen was the main problem due to the presence of temperature fluctuation during the day and night. In line with this study, Kaggwa *et al*. (2011) concluded that the decline of dissolved oxygen is one of the limitations of tropical reservoirs for cage culture of Nile tilapia while it is possible to resolve the anoxic conditions by reducing stocking densities and adjusting the cage depth. Maintaining the physical, chemical and biological parameters are important factors for having a sustainable cage culture (FAO, 2009). Different potential challenges have been identified in the Koga Reservoir cage farm, such as declining water volume during the dry season due to over abstraction for irrigation, poor fish growth, conflict between the community and fishermen, and poor infrastructure such as electricity and market availability. Moreover, some of the bottlenecks in cage culture are a lack of quality extruded fish feed at an affordable price and a lack of access to a higher value market due to poor infrastructure and institutional organization (e.g. Blow and Leonard, 2007).

CONCLUSION AND RECOMMENDATIONS

In Ethiopia, most reservoirs are built for hydropower production but also contribute as alternative sources for the development of fisheries sector and improved livelihoods of communities by creating job opportunities for local landless community members. Koga Reservoir has several benefits for the surrounding communities by providing fishes as well as irrigation and aquaculture services. The current status of capture fisheries in the reservoir showed a decline in total production due to overexploitation. The studied physicochemical parameters of the reservoir water showed good quality for fish and irrigation purposes. Commercial cage culture has been facing several challenges, such as decline in dissolved oxygen, poor growth of fish, declining reservoir water volume due to over abstraction for irrigation, and lack of an accessible market. Therefore, detailed studies are recommended on regular stock assessment, monitoring and evaluating reservoir fish production status. Moreover, governmental attention is needed to establish integrated development (fish and crop) through stock enhancement in reservoirs.

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