Journal of Water Resources and Ocean Science
2020; 9(2): 48-55
http://www.sciencepublishinggroup.com/j/wros
doi: 10.11648/j.wros.20200902.12
ISSN: 2328-7969 (Print); ISSN: 2328-7993 (Online)

Kulfo River Stream Impact on the Sustainability of Aquatic Life in Chamo Lake at Arba Minch

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To cite this article:

Mosisa Teferi Timotewos, Daniel Reddythota. Kulfo River Stream Impact on the Sustainability of Aquatic Life in Chamo Lake at Arba Minch. *Journal of Water Resources and Ocean Science*. Vol. 9, No. 2, 2020, pp. 48-55. doi: 10.11648/j.wros.20200902.12

Received: May 18, 2020; **Accepted**: June 5, 2020; **Published**: June 23, 2020

Abstract: Over the last two decades, most of the water bodies in Ethiopia have become increasingly threatened due to pollution from different sources. Recently, many dead and floating fish on the surface of Chamo Lake at Arba Minch city indicated that lake water quality and ecosystem health had been deteriorated. The deteriorating quality of the lake or river systems is directly linked to the improper existing sewage and city waste disposal systems and untreated wastewater discharged from domestic, agricultural and industrial sources in Arba Minch, Ethiopia. This paper examined 23 water quality parameters to ascertain the water quality of Kulfo river stream as well as Chamo Lake and the impact of Kulfo river stream on Chamo Lake. Analysis of the data revealed that the concentration of Turbidity (21NTU), TDS (1070 mg/l), PO_4^{-3} (1.1 mg/l), Iron (0.64 mg/l), Total Coliform bacteria (646), Ammonia (23.8 mg/l), pH (9.3) and Electrical Conductivity (1715µS/cm) are above the permissible limits in Kulfo river stream which is entering into the Chamo Lake. Besides, the dissolved oxygen levels were also very low as 5.2 mg/l. As per the field observations and laboratory analyses, the dissolved oxygen content in the lake was very low, whereas, the temperature was very high. The Ammonia concentration was very high which could be toxic for aquatic life, especially fish in the lake.

Keywords: Chamo Lake, Dead Fishes, Fertilizers Pollution, Kulfo River Stream, Lake Water Temperature, Water Quality Index

1. Introduction

Ever-increasing population, urbanization, economic activities and modernization are posing problems of sewage disposal, improper management of domestic wastewater and contamination of surface waters like lakes. Land-use change and longer growing seasons could increase the use of fertilizers with subsequent leaching to watercourses, rivers and lakes, increasing the risk of eutrophication and loss of biodiversity [1]. Water scarcity is a growing threat to economic and social development and widespread water pollution in recent decades further complicates the threat, especially in developing countries [2].

Water pollution caused both by anthropogenic activities such as urbanization [3], industrial accidents [4], dam construction [5], bathing, washing, mixing of waste and natural phenomena like soil erosion [6] and climate change [7, 8], and run-off water which render the water to be unsuitable for drinking and aqua-culture as well as a global issue that increases pressures on water resources. Declining water quality is the result of Spatio-temporal changes in sedimentation, temperature, pH, nutrients, heavy metals, toxic organic compounds and pesticides, and so on [9]. The water pollution causes diseases, water scarcity, and mortality of aquatic life affects human life and becomes a hindrance to the development.

Water resources in Ethiopia, especially in the last one decade, have suffered a great deal of stress in terms of water quantity due to different reasons such as the construction of dams on rivers, the global climatic changes, decrease in the annual precipitation rates and improper planning of water uses [10, 11, 12]. Among freshwater resources, lake Chamo is one of the major Rift Valley lakes in Ethiopia and used for various purposes by semi-urban and urban dwellers. It is known for its fish potential and supplies of fresh. The lake is used for the large economic growth of the community in the southern region of Ethiopia.

Of late, the lake has been losing its natural purity, ecological life and the efficiency of fish production. This may be due to many factors that the lake has been subjected to, including pollutants from neighbouring industries, agricultural activities, service rendering centres, urban stormwater and sewage, and other activities in the catchment. Recently, many fishes were found to be dead in the peripheral region of the lake. These include soil erosion, drought, less overflow within the year, the increasing salinity level of the lake, sediment loading, and excessive nutrient loading. These activities aggravate the pollution of the water body and greatly influence the aquatic ecosystem. So it is an important issue that needs to be addressed to protect the quality as well as the aquatic life of the lake.

Therefore, the main aim of this study was to assess the impact of indiscriminate disposal of untreated effluents into the Kulfo river stream, which is draining into the Lake Chamo, on water quality as well as aquatic life by analyzing the current physicochemical status of Kulfo river stream and Lake Chamo. The study also aimed to find the cause of death of fish recently and suggest measures for the protection of aquatic life as well as the water quality of Chamo Lake to the government organizations.

2. Methodology

2.1. Description of the Study Area

The study area, Kulfo river watershed, is located in the Abaya-Chamo sub-basin of the Southern Ethiopian rift valley (Figure 1) and drains to Lake Chamo. It is located between the coordinates of 5°55'N and 6°16'N latitude and 37°18'E and 37°38'E longitude as shown in Figure 1. The Kulfo River is joined by a number of tributaries. The tributaries Baba, Gulando and Yeremo drain the upper part of the basin, whereas the tributaries Wombale and Majale drain the middle part of the watershed. The tributaries Korzha, Ambule, and Titika join Kulfo at the lower part of the basin. It frequently floods in April/October following heavy rains in the upstream highland around Gauge Mountains. The tributaries Baba, Ambule, and others drain into the kulfo river in a short period of time and cause flooding in the low-lying alluvial plains along the river course around the Arba Minch town. Kulfo river basin is the major drainage system in Arba Minch city administration.

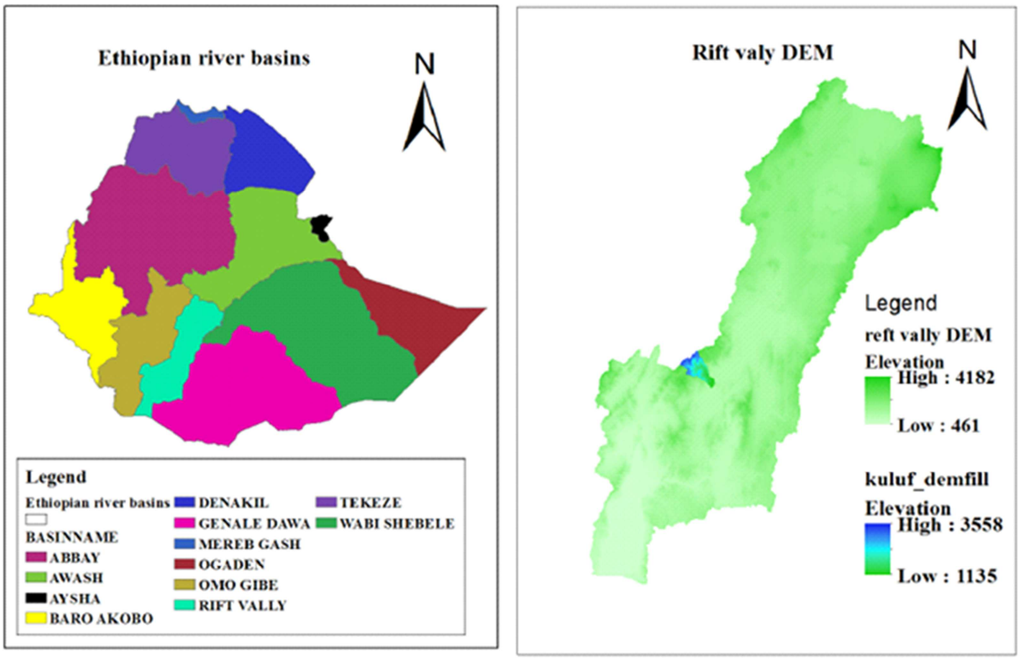

Figure 1. *Ethiopia River basins and Rift valley.*

The study lake, Lake Chamo, is found in the SNNP Region of southern Ethiopia, and it is located in the Great Rift Valley at an elevation of 1,235 meters south of Lake Abaya and the city of Arba Minch, and east of the Guge Mountains. The northern end of the lake lies in the Nechasar National Park, measuring 26 km long and 22 km wide, with a surface area of 551 km^2 and a maximum depth of 13 meters. The specific site lies between the coordinates of 5° 50′ 0″ to 5.83′33″ N latitude and 37° 33′ 0″ to 37.55′ E longitudes at about 505 km south of Addis Ababa. Further, the Lake is rich in a variety of fishes including tiger-fish, giant Nile Perch, catfish and tilapia, which offer fine support. In the bays, a number of hippopotamus emerges at dusk to graze on the grassy shores. Lake Chamo is also a sanctuary for several Nile Crocodiles, which are sometimes up to 7 m in length.

2.2. Sampling Process

Water samples were collected the during dry season (December- February, 2018/19) from five selected sampling sites from Kulfo river stream and five selected sampling sites from Lake Chamo with a 2 L bottle sampler. At each site, 5-6 subsamples were drawn to make a composite sample. The choices of sampling stations (Figure 2) were based on the various zones which are draining into the kulfo river stream and uses of the lake water and their location, importance and magnitude of human influence. 22 physico-chemical and biological parameters, which were believed to govern the water quality, viz., Conductivity, pH, TDS and temperature (°C) were measured.

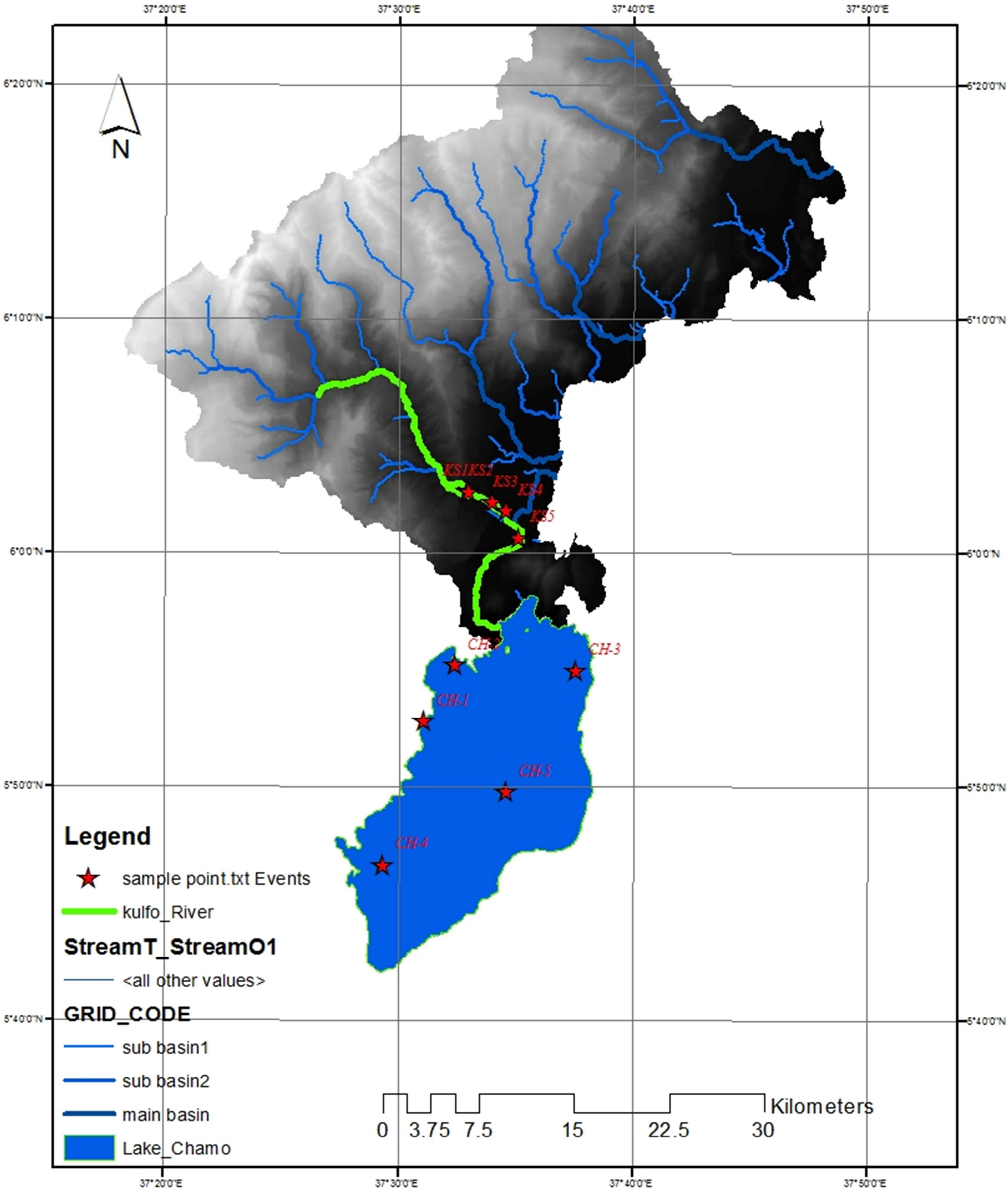

Figure 2. *Sampling points in Kulfo river stream and Chamo Lake.*

Collected depth-integrated samples, by mixing the water samples from different depths (Surface, middle and bottom of the water column). Nutrient concentrations (available and total nitrogen and phosphorus) were measured in the laboratory by employing standard methods. Nitrate-N was determined by the Zinc Reduction Procedure while phosphate was measured calorimetrically by the Ascorbic acid and molybdosilicate methods [11, 13]. Dissolved oxygen was measured with HACH HQ 40d waterproof DO meter and Total alkalinity was determined titrimetricaly using 0.01 NH_4Cl, phenolphthalein, bromocresol green-methyl red indicators and expressed in mg/l of $CaCO_3$.

By using Arc GIS, the kulfo river watershed was delineated indicating the flow direction, flow accumulation and tributaries. Then collected the samples from five outlet points i.e. forest, agricultural area, urban area, grassland area and wetland area which are discharging into the river Kulfo. Samples collected from five different points at various depth and intervals which started from the upper stream end at Michael church up to the entering point of Chamo Lake (mentioned the sample points in Figure 2). Samples collected by using 2L sample bottle were transported within a short period of time to the laboratory. The samples were analyzed based on the standard methods [14]. The water quality index is one of the most effective tools [15, 16] to communicate information on the quality of water to the concerned citizens and policy makers. Four samples from peripheral and one sample from the centre part of the Chamo Lake also collected for analysis of 22 parameters to determine the water quality.

2.3. Statistical Analysis

Different computer programs were used for data interpretation and analysis. SPSS was used for descriptive, correlation and ANOVA tests. Descriptive statistics were used for mean computation. Correlation test has been carried out to assess the relations of physicochemical characteristics of lake water with its biological characteristics. In addition, one way ANOVA was also used. Origin 8.5 was employed for graphical illustrations.

3. Results and Discussion

3.1. Kulfo River Stream Water Quality

The physico-chemical analysis is very essential and important to test the water before it is used for drinking, domestic, agricultural or industrial purpose. Water must be tested with different physicochemical parameters. Water does contain different types of floating, dissolved, suspended and microbiological as well as bacteriological impurities. Some physical test should be performed for testing of its physical appearance, such as temperature, pH, turbidity, TDS, etc., while chemical tests should be performed for its BOD, COD, dissolved oxygen, alkalinity, hardness and other characters.

As per field observation, Kulfo river stream draining into Lake Chamo is only inlet point and there is no out let for this lake Chamo. This indicates that the pollution of the lake is primarily influenced by the Kulfo river stream. Selected 5 sampling points of Kulfo river stream and analytical results have been mentioned in Table 1.

Table 1. *Kulfo river stream water quality.*

Parameters	Samples of Kulfo river stream				
	KS1	**KS2**	**KS3**	**KS4**	**KS5**
Temp (°C)	29.7 ± 0.12	27.9 ± 0.12	25.4 ± 0.12	26.4 ± 0.12	28.2±0.12
pH	6.12 ± 0.05	9.02 ± 0.05	8.38 ± 0.05	8.98 ± 0.05	9.14±0.05
Conductivity (µS/cm)	756 ± 1.19	576 ± 1.20	256 ± 1.19	587 ± 1.19	292±1.20
TP (mg/l)	8.62 ± 0.02	9.51 ± 0.02	8.53 ± 0.02	8.61 ± 0.02	7.69±0.02
PO^{3-}_4-P (mg/l)	5.67 ± 0.04	7.36 ± 0.01	5.48 ± 0.01	6.54 ± 0.01	6.58±0.01
TN (mg/l)	37 ± 0.36	40.31 ± 0. 35	36.44 ± 0.36	35.74 ± 0.36	30.48±0.35
NO3-N (mg/l)	32.52 ± 0.04	35.45 ± 0.04	31.12 ± 0.04	30.36 ± 0.04	28.47±0.04
NO2- N (mg/l)	4.13 ± 0.01	4.09 ± 0.01	2.07 ± 0.01	4.17 ± 0.01	2.11±0.01
TN/TP	4.29 ± 0.21	4.43 ± 0.21	3.88 ± 0.21	4.86 ± 0.21	3.98±0.21
Turbidity (NTU)	21.42 ± 0.11	24.10 ± 0.11	20.15 ± 0.11	22.15 ± 0.11	21.16±0.11
DO (mg/l)	4.26 ± 0.18	6.42 ± 0.18	11.61± 0.18	4.61 ± 0.18	7.26±0.18
TDS (mg/l))	759.3 ± 0.54	578.2 ± 0.58	558 ± 0.58	787 ± 0.58	593±0.58
Chlorophyll a (µg/l)	31.87 ± 0.08	25.17 ± 0.08	24.65± 0.08	26.65 ± 0.08	19.64±0.08
Chloride (mg/l)	137.44 ± 0.10	121.25 ± 0.10	110.92±0.10	116.92± 0.10	112.46±0.16
Total hardness (mg/l)	131.45 ± 0.52	113.72 ± 0.52	112.98±0.52	118.98± 0.52	106.45±0.52
Total Alkalinity as $CaCO_3$	730± 0.51	650± 0.51	750± 0.51	716± 0.51	768± 0.51
BOD_5	68± 0.03	71± 0.03	44± 0.03	51± 0.03	48± 0.03
COD	140± 0.05	148± 0.05	112± 0.05	138± 0.05	104± 0.05
Iron	0.68± 0.01	0.76± 0.01	0.52± 0.01	0.56± 0.01	0.53± 0.01
Total Coliform Bacteria	524	646	514	582	538
Calcium	44± 0.22	52.4± 0.21	34.2± 0.21	44.4± 0.21	46.2± 0.21
Magnesium	21.3± 0.11	20.1± 0.11	20± 0.11	20.3± 0.11	19.2± 0.11

Note: KS1 = Urban area; KS2 = Agricultural area; KS3 = Grassland; KS4 = Forest; KS5 = Wetland

As per the results mentioned in table 1 Sample 1 and 2 are a having high concentration of pollutants and Sample 3, 4 &

5 are collected in downstream of sample 1 and 2 collection points due to this reason, these are also having a high concentration of pollutants which will influence lake water quality. Sample 1 has been collected at the place where domestic wastewater is entering into the Kulfo river stream; due to this, the concentration of organic matter and nutrients was very high. Sample 2 was collected at the place where the agricultural runoff entered into the Kulfo river stream; it had more concentration of Turbidity, phosphates, Nitrates, Ammonia, Calcium. These two samples' concentration impacted the total water quality of the kulfo river stream along with the soil erosion [17]. High load of domestic wastewater which is not treated is entering into the Kulfo river stream and fertilizers which are used by the farmers for agriculture are the key reasons for the pollution of both Kulfo river stream as well as Lake Chamo. Sample 3, 4 & 5 were also having high concentration of pollutants because the grassland zone, forest zone and wetland zone are down streaming points of sample 1 & 2 and near to the entering point of Chamo lake.

3.2. Chamo Lake Water Quality

Chamo lake water samples were collected from the peripheral zones as well as the central zone. For the selected samples analyzed 22 parameters based on the standard methods of APHA (2005). The parameters which are above the permissible limit, those parameters results mentioned below with discussion.

3.2.1. Temperature

Figure 3 shows the concentration of temperatures and pH of the lake Chamo during the dry season. The temperature of the lake water was in the range of 25.3 to 27.4°C (Figure 3). In an established system the water temperature controls the rate of all chemical reactions and affects fish growth, reproduction and immunity. Drastic temperature changes can be fatal to fish. The rates of biological and chemical processes depend on the temperature [18]. Aquatic organisms from microbes to fish are dependent on certain temperature ranges for their optimal health. The low oxygen values coincided with high temperature during the dry season. Temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases); the rate of photosynthesis by aquatic plants; the metabolic rates of aquatic organisms; and the sensitivity of organisms to toxic wastes, parasites and diseases.

The pH value of Chamo lake was in the range of 9.1 to 9.3 (Figure 3), which indicated the alkaline nature of the lake. The higher pH values observed suggests that carbon dioxide, carbonate, bicarbonate equilibrium affects more due to changes in physico-chemical condition. Various factors bring about changes in the pH of water. pH is most important in determining the corrosive nature of water. The reduced rate of photosynthetic activity and the assimilation of carbon dioxide and bicarbonates are ultimately responsible for increased pH.

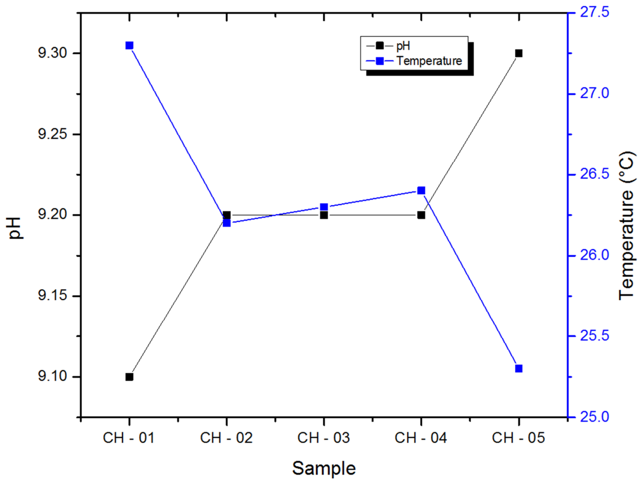

Figure 3. *Temperature and pH of Lake Chamo water samples*

3.2.2. Electrical Conductivity and Alkalinity

The conductivity of the Chamo Lake was found in the range of 1694 to 1715 µS/cm for five samples (Figure 4). All the samples had EC values more than the permissible limit. The alkalinity of the sample 1 (768 mg/l as $CaCO_3$), 2 (750 mg/l as $CaCO_3$) & 5 (730 mg/l as $CaCO_3$) are having a higher concentration than the sample 3 (652 mg/l as $CaCO_3$) & 4 (716 mg/l as $CaCO_3$) and all samples have more than the permissible limit (Figure 4). Conductivity shows a significant correlation with parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids and chemical oxygen demand, chloride and iron concentration of water.

Conductivity in Kulfo river streams affected primarily by the geology of the area through which the water flows, stream that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Discharges of agricultural runoff and domestic wastewater to streams can change the conductivity depending on their make-up. The untreated sewage system might be the reason for high conductivity because of the presence of chloride, phosphate and nitrate.

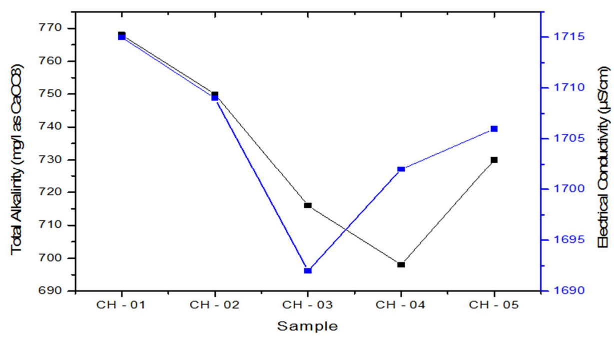

Figure 4. *Total Alkalinity and Electrical Conductivity of Chamo Lake*

3.2.3. Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

TDS values in lake and stream are typically found in the range of 937 to 1070 mg/L for five samples of Lake Chamo

(Figure 5). These values indicate that it is hard water and having high salinity, TDS values are as high as 500 mg/L. It normally represents the amount of organic solids in water. In domestic wastewater, solids are about 50 percent organic, which in turn contaminates the ground as well as Lake Chamo. These solids are generally from plants, dead animal matter and synthetic organic compounds.

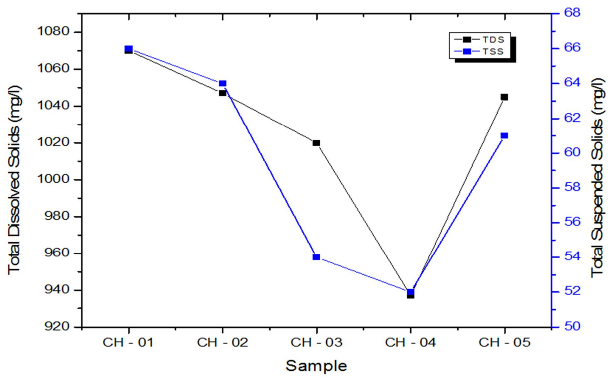

Figure 5. *TDS and TSS of Chamo Lake.*

Solids are found in streams in three forms, suspended, volatile and dissolved. Suspended solids include silt, stirred-up bottom sediment, decaying plant matter, or untreated sewage effluents. The TDS concentration in a body of water is affected by various factors (APHA 2005). Fertilizers from fields and lawns can add a variety of ions to a stream. Increases in TDS can also result from soil erosion from surrounding grassland, forest, wetland, agricultural runoff and domestic wastewater disposal into the Kulfo river stream. Organic matter from untreated domestic wastewater may contribute to higher levels of nitrate or phosphate ions. TDS levels are high, especially due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of animals.

TSS values in Chamo Lake were found in the range of 52 to 66 mg/L for five samples which are higher than the acceptable limit (Figure 5). These suspended solids are present due to the agricultural runoff and untreated domestic wastewater disposal into the kulfo river stream which is entered into the Lake Chamo.

3.2.4. Phosphates and Ammonia

Pure, "elemental" phosphorus (P) is rare. In nature, phosphorus usually exists as part of a phosphate molecule (PO_4). The samples (CH-01 (0.82 mg/l), CH-02 (0.89 mg/l), CH-03 (0.98 mg/l), CH-04 (0.91mg/l) and CH-05 (1.1 mg/l)) of Chamo Lake have more phosphate concentration than the permissible limit (Figure 6).

There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment and commercial cleaning preparations. Phosphorus is an essential nutrient for the plants and animals that make up the aquatic food web. A modest increase in phosphorus can, under the right conditions, set off a whole chain of undesirable events in a stream including accelerated plant growth, algae blooms, low dissolved oxygen and the death of certain fish, invertebrates and other aquatic animals. Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Both organic and inorganic phosphorus can either be dissolved in the water or suspended attached to particles in the water column [19].

Ammonia (NH4-N)

The concentration of Ammonia in Chamo Lake samples was in the range of 19.6mg/l to 23.8 mg/l which are very higher than the permissible limit (Figure 6). Ammonia (NH4-N) concentrations are highly variable during lake seasonal cycles. NH4-N is generated by heterotrophic bacteria as the primary nitrogenous end product of decomposition of organic matter and is readily assimilated by plants in the trophogenic zone [20]. These ammonia high concentrations may due to the domestic wastewater disposal into the kulfo river stream which is entered into the lake Chamo. NH4-N concentrations are usually low in oxygenated waters of oligotrophic to mesotrophic deep lakes because of utilization by plants in the photic zone and nitrification to N oxidized forms. At relatively low dissolved oxygen, nitrification of ammonia ceases, the absorptive capacity of the sediments is reduced and a marked increase of the release of NH4-N from the sediments then occurs.

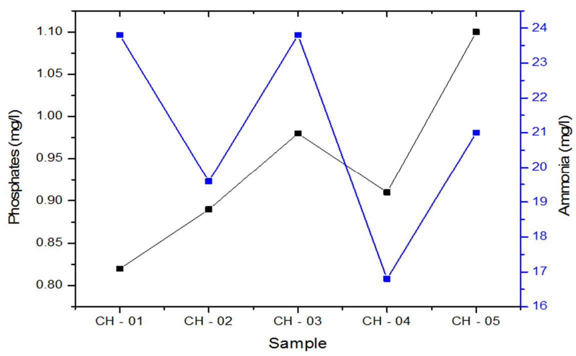

Figure 6. *Phosphates and Ammonia in Chamo Lake*

3.2.5. Dissolved Oxygen (DO)

The mean dissolved oxygen concentration of Chamo Lake was 5.314 mg/l which is very low than the permissible limit of >7 mg/l at 25°C (Figure 7). The DO level of the Chamo Lake ranged between 5.2 mg/l (CH-02) to 5.52 mg/l (CH-03). The domestic wastewater load as well as the high concentration of ammonia leads to the reduction of dissolved oxygen concentration in the Chamo Lake. It can be argued that a low level of DO concentration might be due to high BOD concentration, which indicates the extent of oxygen stress [21] in Chamo Lake. This might be one of the reasons for the death of fish recently in Chamo Lake. The aerobic and anaerobic mineralization of water and sediment crossing point where out oxygen and revitalize nutrients [22, 23]. The reduced DO levels significantly increased the acute toxicity of ammonia to leader prawns (*Penaeus monodon*) [22].

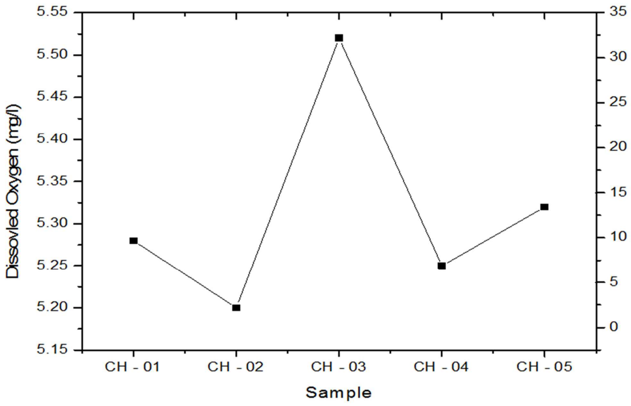

Figure 7. *Dissolved Oxygen in Chamo Lake.*

3.2.6. Biochemical Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)

The BOD has analyzed for five samples of Chamo Lake and the results are in the range of 55 to 60 mg/l which is higher than the permissible limit of 5mg/l (Figure 8). BOD is a measure of the dissolved oxygen consumed by microorganisms during the oxidation of reduced substances in water and wastes. BOD directly affects the amount of dissolved oxygen in lakes and streams. Sources of BOD include leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots and food-processing plants; failing septic systems; and urban storm water runoff.

The discharge of wastes with high levels of BOD can cause water quality problems such as severe dissolved oxygen depletion and fish kills in the receiving water bodies [24]. The greater the BOD, the more rapidly oxygen is depleted in the stream. This means less oxygen is available to higher forms of aquatic life. The consequences of the high BOD are the same as those for low dissolved oxygen aquatic organisms which become stressed, suffocate and die [25]. Chlorine can also affect BOD measurement by inhibiting or killing the microorganisms that decompose the organic and inorganic matter in a sample.

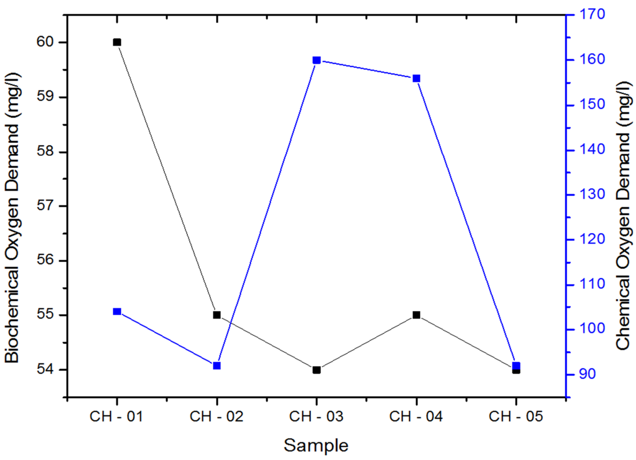

Figure 8. *Biochemical Oxygen Demand and Chemical Oxygen Demand in Chamo Lake.*

COD concentration in the Chamo Lake also showed an analogous trend to that of the BOD. High COD values were noticed at the sampling locations close to the inlet of the Chamo lake (CH – 03 and CH-04) (Figure 8). Average COD concentration of the sampling sites was 120.8 mg/l. The highest COD value was observed at CH-03 (160 mg/l). There is no apparent linear relationship between BOD and COD in relatively clean Chamo lake samples away from the shoreline [25].

However, in the inlet area of Chamo Lake having a relatively high concentration of sewage contamination, a linear correlation does exist between BOD and COD. In the present study, there are numerous sources of Kulfo river stream pollution like untreated domestic wastewater, agricultural runoff and forest area runoff, which ultimately find its way at Chamo Lake. The high volumes of untreated domestic and agricultural area runoff discharges are badly affecting the Chamo Lake water quality as well as aquatic life.

4. Conclusion

The current study evaluated the physicochemical and biological water quality characteristics of Kulfo river stream and Lake Chamo for multiple designated water uses like recreation, economical source and aquatic life. We found that the lake in dry season has shown elevated temperature, nutrient enrichment, low N/P ratios, and high pH. We further observed that increase in conductivity, TDS and salinity (major ions), is making water more turbid which can lead to faster growth of inedible phytoplankton in the peripheral region of the lake. The pH (9.2), EC (1704.4 µS/cm), DO (5.314 mg/l), BOD (56 mg/l), COD (120.8 mg/l), Total alkalinity (722.8 mg/l), Phosphates (0.94 mg/l), TDS (1085.4 mg/l), Ammonia (21 mg/l) and iron (0.566 mg/l) concentrations are above the permissible limits in the Lake Chamo water samples.

It can be concluded that the mean Ammonia concentration was 21 mg/l, which is above the limits, and dissolved oxygen concentration of 5.2 mg/l at 25.2°C temperature was very low at the entering point of the lake Chamo. The higher ammonia concentration might be the reason for fish mortality. The Kulfo river stream was contaminated with agricultural runoff water having more concentration of fertilizers, high concentrated untreated domestic wastewater, and natural soil erosion leading to an increase in turbidity, salinity, nutrient concentrations. This contaminated Kulfo river stream draining into Lake Chamo impacts the water quality, aquatic life and highly valuable fish stock (i.e., yields and diversity). Finally, based on this research, we recommend that the governing bodies take necessary steps to establish the waste water treatment facility near the entering point of the river stream into the Lake Chamo.

Acknowledgements

The authors are grateful to the ArbaMinch Water

Technology Institute, ArbaMinch University (AMU), Ethiopia, for providing laboratory facilities. We are very much thankful to Director, Water Resources Research Center (WRRC) for support to conduct this community research project.

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