Vol. 11(7), pp. 120-128, July 2019
DOI: 10.5897/IJWREE2019.0857
Article Number: C99932861552
ISSN: 2141-6613

http://www.academicjournals.org/IJWREE

ACADEMIC JOURNALS
expand your knowledge

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Evaluation of the current water quality of Lake Hawassa, Ethiopia

Haile Melaku Zigde* and Mohammed Endale Tsegaye

Department of Chemistry, College of Natural and Computational Science, Hawassa University, Hawassa, Ethiopia.

Received 1 May, 2019; Accepted 17 June, 2019

The research aimed to evaluate the current wáter quality of Lake Hawassa in order to identify potential pollution sources and suggest appropriate measures. Physico-chemical water quality parameters have been determined by taking duplicate samples from seven sampling sites and the results were compared with WHO and FAO standards. The findings of the study revealed that the concentration of metals such as manganese (0.83 mg/L), zinc (5.75 mg/L), chromium (0.22 mg/L), phosphate (1.31 mg/L), and biochemical oxygen demand 5 (BOD5, 68.7 mg/L) exceeded WHO standard that could be due to point sources pollution from ceramics, textile, plastics, leather tanning and food processing industries located near the rivers and streams that end up into the lake. Moreover, the study indicated that the lake has also been polluted by non-point source pollution caused by urban stormwater, agricultural runoff, over grazing, deforestation, soil erosion and land development as it was shown with elevated levels of total dissolved solids (TDS, 928.3 mg/L), electrical conductivity (EC, 1851.4 μS/cm), turbidity (47.9 NTUs), fluoride (15.3 mg/L) and potassium (74.2 mg/L). Therefore, intervention measures should be put in place to prevent pollution of the lake.

Key words: Ethiopian Rift Valley Lakes, surface water pollution, water quality parameters, nutrients, metals.

INTRODUCTION

The Ethiopian Rift Valley Lakes (ERVLs) are water resources characterized by a chain of lakes varying in size, hydrological and hydrogeological settings. It constitutes seven main fresh and saline lakes, such as Lake Ziway, Lake Langano, Lake Abiyata, Lake Shalla, Lake Hawassa, Lake Abaya, and Lake Chamo. Among these lakes, Lake Hawassa is the smallest fresh water closed basin lake and is used for various purposes such as small-scale commercial fishing, recreation, irrigation, etc., by semi-urban and urban dwellers (Gebremedhin and Berhanu, 2015; Zinabu and Zerihun, 2002). However, the lake encounters a high risk of pollution from anthropogenic activities, such as urbanization, intense agriculture, rapid industrialization, urban runoff and natural activities such as erosion and heavy rainfall (Katie, 2011; Larissa et al., 2012). Particularly, those industries housed in Hawassa Industrial Park (HIP) and others have been known to release effluents into rivers and streams that end up into the swampy area of the former Lake Shallo from which River Tikurwhua originates (Zinabu and Zerihun, 2002) and fed the lake. This is an immediate threat to the community that uses

*Corresponding author. E-mail: melerevised@gmail.com. Tel: (+251)912371675.

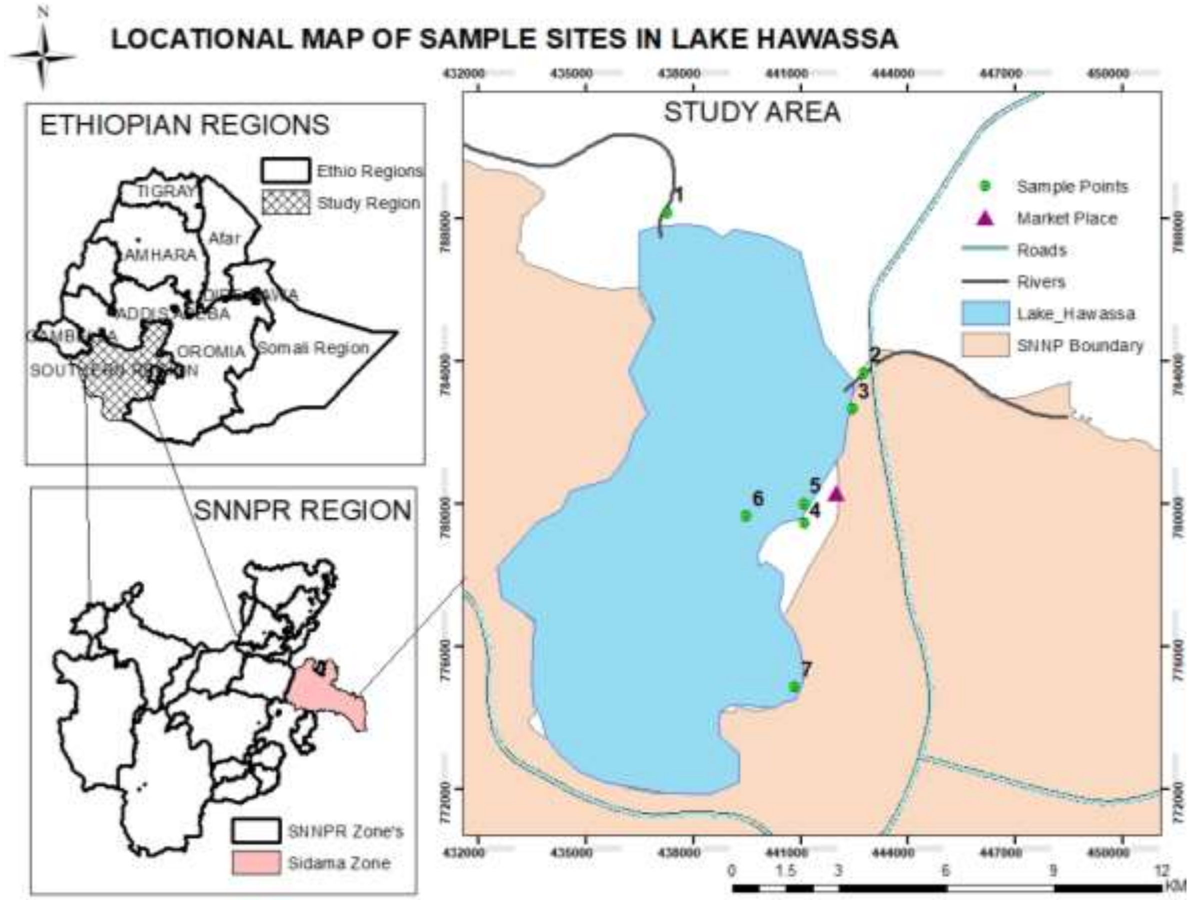

Figure 1. Location map of sample sites in Lake Hawassa.

the rivers and streams for various purposes and to the survival of aquatic life and for the long term survival of the lake. Furthermore, the lake faces a high risk of pollution as a result of natural activities, such as erosion and heavy rainfall. Therefore, the research focussed on assessing the current water quality of Lake Hawassa in order to identify potential pollution sources and suggest appropriate measures by analysing physico-chemical water quality parameters such as pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), turbidity, electrical conductivity (EC), biochemical oxygen demand (BOD), total hardness, total alkalinity, nutrients and concentration of major and minor metal ions for selected sampling sites.

MATERIALS AND METHODS

Description of the study area

This study was carried out in Lake Hawassa, the smallest and the highest in altitude among the Rift valley closed basin lakes, located between 06°58′ to 07° 14′ North latitudes and 38° 22′ to 38° 28′ East longitudes with an elevation of 1697 m above sea level and its annual rainfall average is 969 mm (HALCROW, 2008). The lake is a shallow lake with average depth of 13.3 m and maximum depth of 23.4 m (Mulugeta, 2013). It has a surface area of 90 km^2 and a drainage area of 1250 km^2 (Girma and Ahlgren, 2009) and a water storage capacity of the lake is 1.36 km^3 (Ayenew et al., 2007). The lake is fed by TikurWuha River, a perennial river that drains water from eastern escarpment and a swampy area of the former Lake Shallo (Chaleleka) (Makin et al., 1975). According to Legesse et al. (2003), the climate in Lake Hawassa region is characterized by three main seasons: long rainy season in the summer from June to September is known locally as Kiremt, dry season (locally named as baga) extends between October and February, and "small rain" season (locally named as belg) extends between March and May. The mean annual rainfall is variable ranging from 600 to 1200 mm with a mean value of 961 mm and distributed as 50% for Kiremt (June-September); 20% for baga (October-February) and 30% for belg season (March-May). Due to limited time, money and preliminary observation, a total of seven sampling sites, namely SLW1, SLW2, SLW3, SLW4, SLW5, SLW6, and SLW7 were selected as shown in Figure 1. Five of the total sampling sites were selected within the boundaries of the lake and an additional two sampling sites were selected at the entry point of rivers. The selected sampling sites code, name, and geographical locations are shown in Table 1.

Sampling, sample preparation and analysis

Samples were collected in duplicate and a total of fourteen water

Table 1. Sampling sites code, name, and geographical locations.

Sampling site	Name of sampling site	(GPS)		
		Altitude, m	Latitude (degree, min, s)	Longitude (degree, min, s)
SLW1	Near new Air port	1694	07°07'48.0"	038 °25'55.1"
SLW2	Tikur Wuha River	1672	07°08.4'8.8"	038 °28.9'3.1"
SLW3	Near Haile Resort	1684	07°04.7'7.1"	038 °28.6'8.3"
SLW4	Fikir Hayik	1687	07°03'4.91"	038 °28'.060"
SLW5	Fikir Hayik Marsh	1684	07°03'.21.9"	038 °28'.006"
SLW6	Near Lewi Resort	1683	07°03'011"	038 °27'.7.93"
SLW7	Around Loke	1684	07°00'34.6"	038 °27'52.1"

samples were collected from the selected sampling sites during the belg season (March and April) in 2019. The samples were collected in 1 L capacity plastic bottles and preserved airtight to avoid evaporation. Physical parameters such as TDS, SC, and temperature were determined *in situ* using a Wagtech Conductivity-/-TDS Meter. DO was determined in situ using a HANA Model HI 9143 dissolved oxygen meter. Turbidity and pH were determined onsite using a Wagtech turbidimeter, and a pH meter, respectively. BOD was determined at 20°C for 5 days period using standard method (Delzer and McKenzie, 2003).

These samples were kept refrigerated at -4°C prior to the analysis of nutrients, major and trace metals. Major ions such as K^+ and Mg^{2+} and trace metals such as iron were determined using Photometer 7100 integrated with the Palintest system of water analysis, which uses a reagent systems in tablet or liquid tubetests that react with metal ions to produce either a color or turbid solution so that direct readings in concentration units is possible (Photometer 7100 instruction manual). Fluoride and nutrients such as nitrate, sulfate, and phosphate were determined using Photometer 7100 integrated with the Palintest system of water analysis. Total alkalinity was determined by acid titration with 0.02 N H_2SO_4 and total hardness was determined by ethylenediamine tetra acetic acid (EDTA) titration.

Trace metals such as Mn, Cu, Zn, Cr, and Pb were determined using atomic absorption spectrophotometer (Buck Scientific, Model 210 VGP Atomic absorption spectrophotometer, USA). For the analyses of trace metals, 100.0 mL of unfiltered water sample was taken in a beaker and heated until the volume of the sample solution reached 20.0 mL. Then, the sample solution was cooled and acidified with 2.0 mL of concentrated nitric acid and filtered into a 100.0 mL volumetric flask and made up to the mark with deionized water. Then, the analyses were completed using an atomic absorption spectrophotometer.

Statistical analysis

Descriptive statistics for the selected physico-chemical water quality parameters were carried out. And a one-way analysis of variance (ANOVA) with a post hoc multiple comparisons (Tukey’s test) were used to compare the mean values of results obtained for each sampling sites. The results were compared with WHO and FAO standards.

RESULTS AND DISCUSSION

Physical water quality parameters

The physical water quality parameters investigated is listed in Table 2. High variations in mean values of physical parameters among sites were observed for EC, TDS, and Turbidity. The mean values of the selected physical parameters ranged between 741.7 and 1956.0 µS/cm for EC, 383.7 and 979.3 mg/L for TDS, 8.37 and 177.0 NTUs for turbidity, 5.85 and 9.21 for pH, 4.76 and 8.59 mg/L for dissolved oxygen, 20.6 and 28.3°C for temperature.

pH

Statistical analysis showed that the mean values of pH were significantly different at 95% confidence level among sampling sites. Higher values above the limits were observed at SLW1, SLW3, SLW4, and SLW7 sampling sites. The high value of pH at these sampling sites was attributed to the geological formation of soil reach in carbonates added to the water through erosion and causing the lake to be alkaline. The high pH and the corresponding alkalinity in this study was in agreement with previous study (Ayenew, 2007) findings in which crater lakes are often alkaline where alkalinity is a measure of fertility of the lake at this range rather than pollution indicator. The pH value at SLW5 sampling site (stagnant water near the lake) was slightly acidic (5.85) and below the (WHO, 2004) limits. This might be due to the dissolution of carbon dioxide and nutrients produced during bacterial decomposition of food waste and sewage waste near the lake (Walakira and Okot-okumu, 2011).

Temperature

Temperature is one of the most important physical factors affecting the chemical and biological reaction in water. Higher temperatures support faster growth rates and enable some biota to attain significant populations (UNESCO/WHO/UNEP, 1996). Water temperature obtained during the sampling periods for all sites were insignificant at 95% confidence level and water temperature varies from 20.56 to 28.30°C. Higher values were recorded at SLW6 and sampling site; whereas, the

Table 2. Physical parameters result (Mean ± SD, n=6) at the sampling sites in Lake Hawassa.

Sampling site	pH	Temp (°C)	TDS (ppm)	DO (ppm)	Turbidity (NTUs)	EC (μS/cm)
SLW1	9.17 ± 0.05	25.3 ± 0.52	979.3 ± 1.5	7.84 ± 0.03	8.71 ± 0.1	1956 ± 1.7
SLW2	6.76 ± 0.4	21.33 ± 0.5	517.7 ± 0.6	4.76 ± 0.02	26.56 ± 1.2	1029.7 ± 1.2
SLW3	9.21 ± 0.04	20.6 ± 0.3	882.7 ± 1.1	5.43 ± 0.5	19.3 ± 0.9	1664.3 ± 6.0
SLW4	8.56 ± 0.1	24.5 ± 0.1	856 ± 2.6	8.59 ± 0.3	9.68 ± 0.2	1624 ± 4.5
SLW5	5.85 ± 0.1	25.5 ± 0.34	383.7 ± 0.6	8.07 ± 0.03	177.0 ± 1.2	741.7 ± 0.5
SLW6	8.16 ± 0.1	28.3 ± 0.1	912 ± 0.5	8.23 ± 0.1	8.37 ± 0.1	1831 ± 0.6
SLW7	8.86 ± 0.05	25.7 ± 0.05	833.3 ± 1.5	8.06 ± 0.1	27.7 ± 0.5	1842.3 ± 1.5
Average	8.67 ± 0.7	26.7 ± 2.0	928.3 ± 72.1	7.22 ± 0.9	47.9 ± 55.4	1851.4 ± 148
WHO (2004)	6.5 to 8.5	< 40.0	500	5.0 to 7.0	5.0	750
FAO (1985)	6.0 to 8.5	-	2000	> 4.0	-	3000

minimum value at SLW3 sampling site. There was a slight fluctuation in temperature that might be due to variation in the weather conditions. Nonetheless, temperature of Hawassa Lake water is likely suitable for aquatic lives.

Turbidity

Turbidity in natural waters is commonly caused by the presence of clay, silt, organic matter, algae, and other microorganisms (Lamb, 1985). The turbidity value of the sampling sites ranges from 8.37 to 177.0 NTUs with an overall mean value of 47.9 NTUs and this was higher than (WHO, 2004) standard for drinking purposes. The highest value of turbidity was recorded at SLW5 (177 ± 3.21 NTUs) followed by SLW7 sampling sites; whereas, the minimum value of turbidity was recorded at SLW6 (8.37 ± 0.14 NTUs) sampling site. The high values of turbidity could be mainly attributed to surface runoff from the catchment area as well as from inflowing perennial river loaded with silt during the sampling periods of small rainy season.

Electrical cconductivity (EC)

Electrical conductivity is a measure of how much total salt is present in the water. The more the ions existed, the higher the conductivity formed (Mosley et al., 2004). Electrical conductivity values range from 741.7 to 1956.0 μS/cm. The highest value was recorded at SLW1 sampling site, followed by SLW7, SLW6, SLW3, SLW4, and SLW2 sampling sites, respectively. These could be attributed to influx of dissolved solutes from the surrounding urban areas, agricultural fields and institutional effluents. All EC values recorded were higher than WHO standards for drinking purposes, except SLW5 (741.66 μS/cm) sampling site and lower than (FAO, 1985) standard for irrigation. The low value recorded at SLW5 might be due to adsorption of dissolved ions into organic particulates and suspended solids found in the river.

Total dissolved solids (TDS)

TDS emanating from the discharge of various chemicals used as food preservatives in food processing industry, ceramic and textile industry, waste from Hospitals, etc. The discharge of wastewater with a high TDS level into water bodies would have adverse impact on aquatic life and exacerbate corrosion in water networks (LVEMP, 2002). For all the other sampling sites, except for SLW5, the average value of TDS exceeds the maximum permissible limits (WHO, 2004) for the drinking purpose but within the limit given by FAO (1985) for irrigation water. The high value of TDS at these sampling sites were attributed to influx of dissolved solutes from agricultural fields, discharge of domestic waste from the town and other human activities like washing of clothes or different vehicle at and around the lake. Lower values of TDS below the WHO (2004) limits were observed at SLW5 sampling site and could be due to the dilution effect from the inflow of water during the sampling periods of small rainy season.

Dissolved oxygen (DO)

Oxygen is the main indicator of water quality in surface water. DO values in the present study ranged from 4.76 to 8.59 mg/L. The highest recorded values of DO were at SLW4 sampling site followed by SLW6 SLW5, SLW7, and SLW1 indicating the sampling sites were relatively free of organic waste during the study periods. However, lowest DO value was recorded at SLW2 (4.76 mg/L) and these values were below the permissible limits set by WHO and could be due to the decomposition of excess nutrient and biodegradable organic matter (Fikresilasie, 2011).

Table 3. Nutrient and BOD5, total hardness and alkalinity result (Mean ± SD, n=6) at the sampling sites in Lake Hawassa.

Sampling site	Nitrate (NO_3-)	Sulfate (SO_4^{2-})	Phosphate (PO_4^{3-})	Fluoride (F^-)	BOD5	Total Hardness	Total Alkalinity
	ppm	ppm	ppm	ppm	ppm	mg/L $CaCO_3$	mg/L $CaCO_3$
SLW1	4.3 ± 0.5	12.4 ± 0.7	1.26 ± 0.1	17.3 ± 0.7	63.4 ± 0.4	60 ± 2.0	14.6 ± 5.8
SLW2	3.13 ± 0.2	12.4 ± 0.4	1.31 ± 0.04	12.13 ± 0.7	168.2 ± 2.5	52.6 ± 1.1	14.6 ± 0.6
SLW3	3.43 ± 0.2	12.8 ± 0.4	0.3 ± 0.1	11.8 ± 0.9	159.0 ± 0.2	64 ± 0.5	11.3 ± 0.6
SLW4	4.71 ± 0.2	8.4 ± 0.1	1.33 ± 0.1	12.8 ± 0.4	161.2 ± 0.3	64 ± 1.0	11.3 ± 0.6
SLW5	2.83 ± 0.03	18.5 ± 0.6	1.9 ± 0.01	13.8 ± 0.4	153.1 ± 0.5	72.6 ± 1.1	19.3 ± 0.57
SLW6	3.68 ± 0.5	10.6 ± 0.3	1.34 ± 0.05	13.23 ± 0.8	156.5 ± 0.3	71.6 ± 1.5	14.3 ± 0.57
SLW7	6.79 ± 0.5	10.9 ± 0.5	1.36 ± 0.04	13.2 ± 0.6	74 ± 0.2	57.3 ± 1.5	10.0 ± 0.1
Average total	5.54 ± 1.8	11.6 ± 1.1	1.31 ± 0.1	15.3 ± 2.9	68.7 ± 7.5	58.6 ± 1.9	14.6 ± 3.3
WHO (2008)	45.0	250.0	0.1	1.5	2.0 - 5.0	300	120
FAO (1985)	50.0	400.0	2.0	-	8.0	-	-

Selected nutrients in sampled sites of Lake Hawassa

The mean concentrations of the selected nutrient, BOD5, total hardness and alkalinity are shown in Table 3. The mean values of the selected physical parameters ranged between 2.83 and 6.79 mg/L for nitrate, 8.4 and 18.5 mg/L for sulfate, 0.3 and 1.9 mg/L for phosphate, 11.8 and 17.3 mg/L for fluoride, 63.4 and 168.2 mg/L for BOD5, 52.6 and 72.6 mg/L $CaCO_3$ for total hardness, and 10.0 and 19.3 mg/L $CaCO_3$ for total alkalinity.

Nitrate-

The mean concentration of nitrate recorded at all sampling sites were within the limit of WHO (2008) and FAO (1985) standards. However, relatively highest concentration of nitrate was recorded at SLW7 (6.79 ± 0.5 mg/L) sampling site and this could be due to agricultural runoff and certain industrial wastes. The lowest nitrate concentration was recorded at SLW5 (2.83 ± 0.03 mg/L) sampling site showing that the sampling site was relatively less polluted by nitrogenous materials.

Sulfate

The mean concentration of sulfate recorded at all sampling sites were within the limit of WHO and FAO standards with the highest mean value measured at SLW5 (18.6 ± 0.6 mg/L) sampling site and the lowest at SLW4 (8.4 ± 0.1 mg/L) sampling site. High concentration of sulfate at SLW4 sampling site could be related to the discharge of sulfate containing municipal sewages and surface runoff that contain organic fertilizers from agricultural activities or due to the variability of the distribution of soluble sulfate salts in the sampling sites.

Orthophosphate

The mean concentration of orthophosphate recorded at all sampling sites were higher than the limit of WHO (2008) and lower than FAO (1985) standards with the highest mean value measured at SLW5 (1.90 ± 0.01 mg/L) sampling site. This could be due to pollution from domestic sewages, discharge of waste that led to eutrophication and surface runoff from phosphate containing fertilizers.

Fluoride

The mean concentration of fluoride recorded at all sampling sites was higher than the limit of WHO (2008) standards with the highest value measured at SLW1 (17.3 ± 0.7 mg/L) sampling site and the lowest at SLW3 (11.7 ± 0.3 mg/L) sampling site. Highest concentration of fluoride at the sampling sites prominently associated with a natural weathering of mineral bed rocks (WHO, 2008) or seepage of ground water into the lake. It is also a common problem mainly in rift valley lakes of Eastern Africa countries due to geological factors (Tamiru, 2006).

Table 4. Mean concentration (mean ± SD in mg/L, n=6) of metals at the sampling sites in Lake Hawassa.

Sampling site	Iron (Fe)	Magnesium (Mg)	Potassium (K)	Chromium (Cr)	Copper (Cu)	Zinc (Zn)	Manganes (Mn)
	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SLW1	0.12 ± 0.03	29.0 ± 1.1	84.3 ± 0.1	0.17 ± 0.01	ND	7.4 ± 0.2	ND
SLW2	0.58 ± 0.03	26.8 ± 1.4	54.0 ± 1.1	0.3 ± 0.01	0.07 ± 0.01	1.1 ± 0.05	1.5 ± 0.05
SLW3	0.25 ± 0.02	19.8 ± 1.0	82.2 ± 0.7	0.45 ± 0.03	0.06 ± 0.01	1.5 ± 0.05	ND
SLW4	0.6 ± 0.1	32.2 ± 0.8	32.2 ± 0.8	0.42 ± 0.01	ND	3.0 ± 0.04	0.2 ± 0.01
SLW5	0.75 ± 0.1	24.2 ± 0.3	81.2 ± 1.5	0.3 ± 0.02	0.03 ± 0.02	0.4 ± 0.01	1.8 ± 0.01
SLW6	0.73 ± 0.04	26.3 ± 0.7	62.6 ± 0.3	0.58 ± 0.03	0.03 ± 0.02	0.2 ± 0.05	0.13 ± 0.01
SLW7	0.14 ± 0.03	26.3 ± 1.1	64 ± 0.3	0.26 ± 0.02	0.03 ± 0.02	4.1 ± 0.1	0.16 ± 0.01
Average total	0.13 ± 0.01	27.6 ± 1.9	74.2 ± 14.3	0.22 ± 0.06	0.05 ± 0.03	5.75 ± 2.3	0.83 ± 0.9
WHO (2008)	0.3	30.0	20.0	0.05	2.0	5.0	0.1
FAO (1985)	-	120.0	-	-	-	-	-

Total hardness

The total hardness of water recorded at all sampling sites was lower than the limit of WHO (2008) standards with the highest mean value measured at SLW5 (72.6 ± 1.1 mg/L $CaCO_3$) sampling site and could be due to industrial effluents, and urban and rural runoff. The lowest total hardness value recorded at SLW2 (52.6 ± 1.1 mg/L $CaCO_3$) sampling site.

Total alkalinity

The alkalinity of surface water is primarily a function of carbonate, hydroxide content and includes the contributions from borates, phosphates, silicates and other bases. Total alkalinity measures the ability of water to neutralize the acids. The total alkalinity of water recorded at all sampling sites was lower than the limit of WHO (2008) standards with the highest mean value measured at SLW5 (19.3 ± 0.57 mg/L $CaCO_3$) and the lowest value at SLW7 (10.0±0.1 mg/L $CaCO_3$). Highest value of total alkalinity at the sampling sites prominently associated with waste discharge and microbial decomposition of organic matter in the sampling sites.

Biochemical oxygen demand (BOD_5)

The mean concentration of value of BOD_5 was the highest at SLW2 (Tikurwuha River) (168.2 ± 2.5 mg/L) followed by SLW4 (Fikir Hayik) (161.2 ± 0.3 mg/L), SLW3 (Near Haile Resort) (159.0 ± 0.2 mg/L), and SLW6 (Near Lewi Resort) (156.5 ± 0.3 mg/L). The lowest BOD_5 value recorded at SLW1 (Near Airport) and SLW7 (Around Loke) were 63.4 ± 0.4 and 74 ± 0.2 mg/L, respectively. The values of BOD5 recorded at all sampling sites exceed the maximum permissible limits of WHO and FAO standards. These could be due to continued discharge of domestic waste from the city, industries, agricultural activities, and waste from fish market that is near to the lake and other human activities that could produce organic wastes.

Metals in sampled sites of Lake Hawassa

The mean concentrations of the selected metals concentration are shown in Table 4.

Metals concentration

The mean concentration of major and trace metals analyzed ranged between 0.12 and 0.75 mg/L for Iron, 19.8 and 32.2 mg/L for Magnesium, 32.2 and 84.3 mg/L for Potassium, 0.17 and 0.58 mg/L for Chromium, 0.03 and 0.07 mg/L for Copper, 0.2 and 7.4 mg/L for Zinc, and 0.13 and 1.8 mg/L for Manganese. Lead and cadmium were not detected in all sampling sites as their concentration was below the detection limit (0.04 mg/L for Pb and 0.01 mg/L for Cd) of Buck Scientific, Model 210 VGP Atomic absorption spectrophotometer.

Magnesium

The average values of major metals concentration were in the following descending order: K > Mg > Fe. The recorded value for magnesium concentrations lies within the prescribed limit of WHO and FAO except at SLW4 (32.2 ± 0.8 mg/L) sampling site and could be originated from industrial effluents containing salts of magnesium or other magnesium sources carried by runoff from rural agricultural lands and urban wastewater. The minimum concentration of magnesium was recorded at SLW3 (19.8 ± 1.0 mg/L) sampling site.

Potassium

The average concentration of potassium exceeds the maximum permissible limits of WHO (2008) in all of the sampling sites. Highest potassium concentration recorded at SLW1 (84.3 ± 0.1 mg/L) sampling site followed by SLW3, SLW5, SLW7, SLW6, SLW2, and SLW4 sampling sites. This could be due to the effect of hospital effluents, septic system, and other anthropogenic activities besides the natural sources (Worako, 2015) or waste fruits and vegetables containing high-level potassium could be another source.

Iron

The concentrations of iron recorded at all sampling sites exceed the maximum permissible limits of WHO standard. Highest iron concentration recorded at SLW5 (0.75 ± 0.1 mg/L) sampling site followed by SLW6, SLW4, SLW2, SLW3, SLW7, and SLW1 sampling sites. This could be due to corrosion of metallic materials made of iron and from a certain industrial processes.

Copper

In two sampling sites (SLW1 and SLW4), copper was not recorded. The maximum concentration of copper were recorded at SLW2 (Tikurwuha River) (0.07 ± 0.01 mg/L) and SLW3 (Near Haile Resort) (0.06 ± 0.01 mg/L) sampling sites that exceeded WHO standard and could be due to incineration of waste, industrial discharge, sewage disposal and antifouling paints (Moore et al., 2013). However, the concentrations of copper in the rest of the sampling sites were within the maximum permissible limits of WHO standard.

Zinc

The concentrations of zinc recorded at all sampling sites except at SLW1 (7.4 ± 0.2 mg/L), were within the maximum permissible limits of WHO (2008) standard and could be due to storm water draining from vehicle oil, grease and lubricants spill on roads, vehicle repairing and washing areas as well as from industrial effluent containing leached zinc from pipe coatings, or raw chemicals used up by industries (EEPA, 2003).

Manganese

Highest concentration of manganese was recorded at SLW5 (1.80 ± 0.01 mg/L) and SLW2 (1.5 ± 0.05 mg/L) sampling sites which exceeded WHO standard. Manganese was not detected in SLW1 and SLW3 sampling sites and the lowest concentration of manganese was recorded at SLW6.

Chromium

The concentrations of chromium recorded at all sampling sites exceed the maximum permissible limits of WHO standard. Highest chromium concentration recorded at SLW6 (Near Lewi Resort) (0.58 ± 0.03 mg/L) sampling site followed by SLW3 (Near Haile Resort), SLW4, SLW2, SLW5, SLW7, and SLW1 sampling sites. These might be attributed to industrial discharge from pigments, paints, ceramic, glass and leather tanning industries as well as domestic wastewater composed of grey water that may consist of: the bath, dishwasher products, personal care products and laundry detergents; which are good sources of these metal elements (Tjandraatmadja et al., 2008).

Comparison of results with previous work

In the present study, seven sampling sites were selected to determine the physico-chemical water quality parameters of the lake but in the previous studies ten sampling sites (Abate et al., 2015) and four sampling sites (Praveen and Mukemil, 2015) were selected. The physico-chemical and biological water quality characteristic of the lake Hawassa analyzed by different researchers in different periods of time is shown in Table 5.

The concentration of iron, manganese, copper, lead, and chromium in the previous studies were within the permissible limit set by WHO (2008) standard or else not detected at all. However, in the present study the concentration of these metals exceeded WHO limit for drinking purpose. These might be due to the accumulation of these metals into the lake through effluent discharge from ceramic, textile and leather tanning industries located along the streams that fed into Tikurwuha River (Berehanu et al., 2015).

Both in the present and previous study, the

Table 5. Mean values of physico-chemical water quality parameters of Hawassa Lake reported by researchers.

Parameter	Worako AW (2015)	Abate et al. (2015)	Praveen and Mukemil (2015)	Present work (2019)
pH	7.54	7.54	7.67	8.67
Temperature	21.2	21.2	25.7	26.7
DO	17.8	17.8	16.9	7.22
BOD5	117	117	-	68.7
TDS	450.1	450.1	547.5	928.3
EC	750	750	806.3	1851.4
Turbidity	8.44	8.44	11.5	47.9
Total hardness	121.9	121.9	-	58.6
Total alkalinity	-	-	--	14.6
Nitrate	5.27	5.27	14.7	5.54
Sulfate	-	-	-	11.6
Phosphate	1.12	1.12	-	1.31
Fluoride	12.8	12.8	12.1	15.3
Potassium	74.1	74.1	-	74.2
Magnesium	28.1	28.1	26.2	27.6
Iron	0.085	0.085	0.06	0.13
Manganese	0.09	0.09	0.004	0.83
Zinc	0.19	0.19	-	5.75
Copper	0.01	0.01	-	0.05
Lead	ND	ND	-	ND
Chromium	ND	ND	-	0.22
Cadmium	ND	ND	-	ND

All units except temperature (°C), turbidity (NTUs), SC (μS/cm), and pH (in pH scale) are in mg/L. Total hardness and alkalinities are expressed as mg/L of $CaCO_3$. ND: Not detected.

concentration of potassium, phosphate, and fluoride were found to be higher than the limit of WHO (2008) standards. These could be due to effluent discharge from Hawassa Referral Hospital (Abate et al., 2015), Resorts and hotels, domestic sewages or surface runoff from phosphate containing fertilizers. Turbidity of the lake exceeded WHO standard and it has shown an increase in its value through time. These might be due to a steady increase in suspended sediment due to a polluted tributary and surface runoff or the development of an algal bloom on the lake. A decrease in the concentration of DO was observed as time goes by. And these might be due to the decomposition of accumulated organic waste by microbial that deplete the concentration of oxygen. In all of these studies, the value of pH, temperature, total hardness, nitrate, sulphate and magnesium were found to be within the permissible limit set by WHO.

Conclusion

The study has shown that the concentration of metals such as manganese, zinc, chromium and nutrients like phosphate, BOD5 were found above the recommended WHO (2008) standard for drinking purpose and this could have an adverse impact on aquatic life and humans and animals that uses the lake water for various purpose. Elevated levels of these metals and nutrients could be due to point source pollution from ceramics, textile, plastics, leather tanning and food processing industries located near the rivers and streams that end up into the lake. Thus, Hawassa City Administration should take measures to check the effluents of those industries in order to meet the requirements of effluent discharge limits and prohibitions. Furthermore, the lake also faces non-point source pollution caused by urban stormwater, agricultural runoff, over grazing, deforestation, soil erosion and land development as it was indicated by elevated levels of TDS, EC, turbidity, fluoride and potassium. As a result, Hawassa City Administration along with other NGOs, physical soil and water conservation measures with ultimate intention of reducing sever soil erosion and its associated impact in communal and private lands of the upper catchments of Lake Hawassa watershed should be put in place in order to rehabilitate the condition of the lake. Nonetheless, the condition of the lake will continue to deteriorate unless intervention measures are put in place.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

ACKNOWLEDGEMENTS

The authors thank the Rift Valley Lakes Basin Branch Authority of Hawassa, Ethiopia, for their cooperation. They also thank Hawassa University for supporting the research.

REFERENCES

Abate B, Woldesenbet A, Fitamo D (2015). Water quality assessment of Lake Hawassa for multiple designated water uses. Water Utility Journal 9:47-60.

Ayenew T (2007). Water management problems in the Ethiopian rift: Challenges for development. Journal of African Earth Sciences 48(2):222-236.

Ayenew T, Becht R, Lieshout A, Gebreegziabher Y, Legesse D, Onyando J (2007). Hydrodynamics of topographically closed lakes in the Ethio-Kenyan Rift: the case of lakes Awassa and Naivasha. Journal of Spatial Hydrology 7(1).

Berehanu B, Lemma B, Tekle-Giorgis Y (2015). Chemical Composition of Industrial Effluents and Their Effect on the Survival of Fish and Eutrophication of Lake Hawassa, Southern Ethiopia. Journal of Environmental Protection 6:792-803.

Delzer GC, McKenzie SW (2003). Five-day biochemical oxygen demand: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7 (3d ed.), section 7.0, accessed February, 2019, from http://pubs.water.usgs.gov/twri9A/.

EEPA (2003). Guideline Ambient Environment Standards for Ethiopia. Prepared by EPA and UNIDO under ESDI project US/ETH/99/068/Ethiopia, Addiss Ababa.

Food and Agriculture Organization (FAO) (1985). Water Quality for Agriculture. Food and Agriculture Organization. Rome, Italy.

Fikresilasie T (2011). Impact of brewery effluent on river water quality: the case of Meta Abo Brewery Factory and Finchewa River in Sebeta, Ethiopia. Addis Ababa University Laibraries. URI: http://localhost:80/xmlui/handle/123456789/7407.

Gebremedhin K, Berhanu T (2015). Determination of some selected heavy metals in fish and water samples from Lake Hawassa and Ziway Lakes. Science Journal of Analytical Chemistry 3:10-16.

Girma T, Ahlgren G (2009). Seasonal Variations in Phytoplankton biomass and primary production in the Ethiopian Rift Valley lakes, Ziway, Awassa and Chamo-The basis of fish production. Elsevier Science, Limnologica 40:330-342.

HALCROWind (2008). Rift Valley Lakes Basin Integrated Resources Development. Master Plan Study Project, Draft Phase 2 Report Part II Prefeasibility Studies, Halcrow Group Limited and Generation Integrated Rural Development (GIRD) consultants. Unpublished report. Addis Ababa. http://open_jicareport.jica.go.jp/pdf/12066403_03.pdf

Katie G (2011). Environmental Policy Review: Lake Water Management in three Ethiopian Rift Valley Watersheds.

Lamb JC (1985). Water Quality and its control. John Wiley and sons.

Larissa D, Mesfin M, Elias D (2012). Assessment of heavy metals in water samples and tissues of edible fish species from Awassa and Koka Rift Val Lakes, Ethiopia. Environmental monitoring Assessment 185(4).

Legesse D, Vallet-Coulomb C, Gasse F (2003). Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. Journal of Hydrology 275:67-85.

LVEMP (2002). Integrated water quality/limnology study of Lake Victoria. Final technical report, COWI/DHI, Denmark. https://www.oceandocs.org/bitstream/handle/1834/7149/ktf0090.pdf?sequence=1&isAllowed=y

Makin MJ, Kingham TJ, Waddams AE, Birchall CJ, Teffera T (1975). Development Projects in the Southern Rift Valley of Ethiopia. Land resource study no., 21. England: Land Resource Division, Ministry of Overseas Development.

Moore RB, Milstead WB, Hollister JW, Walker HA (2013). Estimating Summer Nutrient Concentrations in Northeastern Lakes from SPARROW Load Predictions and Modeled Lake Depth and Volume. PLoS ONE 8(11):e81457.

Mosley L, Sarabjeet S, Aalbersberg B (2004). Water quality monitoring in Pacific Island countries: Handbook for water quality managers & laboratories, 1st Edition. ISSN: 1605-4377: SOPAC, The University of the South Pacific. Suva Fiji Islands.

Mulugeta DB (2013). The Impact of Sedimentation and Climate Variability on the Hydrological Statur of Lake Hawassa, South Ethiopia. Dissertation, Bonn, Rheinische Friedrich-Wilhelms-Universität Bonn. Photometer instructional manual for Palintest test, https://www.palintest.com/en/products/photometer-7100

Praveen M, Mukemil KO (2015). CME water quality index and assessment of physico-chemical parameters of Lake Hawassa, Ethiopia. International Journal of Recent Scientific Research 6(6):7891-7894.

Tamiru A (2006). Ground water occurrence in Ethiopia, Addis Ababa. UNESCO P 75.

Tjandraatmadja G, Diaper C, Gozukara Y, Burch L, Sheedy C, Price G (2008). Sources of priority contaminants in domestic wastewater: Contaminant contribution from household products. Commonwealth Scientific and Industrial Research Organisation (CSIRO): Water for a Healthy Country National Research Flagship.

United Nations Educational, Scientific and Cultural Organization (UNESCO) World Healthorganization (WHO) United Nations Environment Programme (UNEP) (1996). Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring, 2nd Edition. P 651.

Walakira P, Okot-Okumu J (2011). Impact of Industrial Effluents on Water Quality of Streams in Nakawa-Ntinda, Uganda. Journal of Applied Sciences and Environmental Management 15(2):289-296.

World Health Organization (2008). Guidelines to drinking water quality. 3rd ed., 1:1-666. Geneva. https://www.who.int/water_sanitation_health/dwq/fulltext.pdf

World Health Organization (2004). Guidelines for drinking-water quality. 3rd ed., 1: Geneva. https://www.who.int/water_sanitation_health/dwq/GDWQ2004web.pdf

Worako AW (2015). Physicochemical and biological water quality assessment of Lake Hawassa for multiple designated water use. Journal of Urban and Environmental Engineering 9(2):146-157.

Zinabu GM, Zerihun D (2002). The chemical composition of the effluent from Awassa Textile Factory and its effects on aquatic Biota. Ethiopian Journal of Science 25(2):263-274.