Water Utility Journal 9: 47-60, 2015.

Water quality assessment of lake Hawassa for multiple designated water uses

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Abstract: Lake Hawassa is one of the Major Ethiopian Rift Valley Lakes which has a closed basin system. It receives inflow from the only perennial River *Tikurwuha* and runoff from the remaining sub-catchment. Quality of lake water is vital for the surrounding community for proper and safe use of the lake. The present study was designed to examine the physicochemical and biological water quality suitability for multiple purposes and to determine trophic state index of the lake for a period of three months from December to February, 2011/12. Water samples were collected from the lake on monthly basis and analyzed for all water quality parameters by following standard methods. Data analysis was performed by descriptive, multivariate analysis (MANOVA) and Tukey-Kramer test. The overall water quality parameters analytical results have been observed as pH (7.54), TDS (450.1), temp.(21.23°C), DO (17.85), turbidity (8.44NTU), COD (48.73), BOD_5 (117), F^- (12.8), NO_3^- (5.27), PO_4^{3-} (1.12), NO_2^- (0.04), TN (5.42), TP (0.37), Cl^- (30.84), Mn(0.09), Zn(0.19), Na^+(331), Chll-a(25.45μg/l), TC(11,883MPN/100ml) and FC (99.67MPN/100ml) and units for others in mg/l. On the other hand, the value of indices for irrigation water quality was SAR (12.2-16), SSP (83.77-84.34%), MAR (93.83-95.37%) and KR (5.71-7.18). The values of the whole analyzed parameters have shown significant variation in site ($P<0.05$). As irrigation water quality mainly focuses on the indices of SAR and EC/TDS, the lake water is in good condition for the purpose. The values of trace heavy metals were under permissible limits for multiple aspects. On average, the trophic state index of the Lake Hawassa was hypereutrophic (TSI=72.6), as Carlson value category. In general, the lake water is not suitable for drinking, recreational and irrigation of some raw consuming crops but it's suitable for aquatic life.

Key words: Aquatic life, drinking water, irrigation water, Lake Hawassa, trophic state index, water quality parameters.

1. INTRODUCTION

Due to increasing population growth, human water demand for domestic, industrial and agricultural purposes to supply adequate food for the nation is increasing (UNDP, 2006) and water becoming a scarce commodity in most part of the world. In the world peoples living under water-stressed condition ranges are from 1.4 billion to 2.1 billion (Vorosmarty et al., 2000; Oki et al., 2003; Arnell et al., 2004). Water-stressed condition refers to per capita water availability below 1,000m^3 per year or based on the long-term average annual runoff coefficient above 0.4 (World Bank, 1992).

The quality of water is highly important component to understand the healthiness of a water body and it's a critical factor affecting human health and welfare (Yasser, 2007). Water quality refers to the physical, chemical and biological characteristics of the water. Studies showed that approximately 3.1% of deaths (1.7 million) and 3.7% of disability-adjusted-life-years (54.2 million) worldwide are attributable to unsafe water, poor sanitation and hygiene (WHO, 2005).

Physicochemical and biological water quality indicators will be affected by various ways. The main causes for the water quality deteriorations are anthropogenic and natural agents (Chaterjee and Raziuddin, 2002). Some of the nature and human induced factors which affect the quality of water for various purposes are geology, hydrology, natural hazards, sedimentation/erosion, agricultural activities, industrial, mining, fishing, sewage discharging/disposal, deforestation, and other commercial activities. These activities aggravate the pollution of water body and greatly influence the quality of water (Zinabu, 2002; Tamiru, 2006).

Ethiopia is one of the tropical countries, which is gifted with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance. Lake Hawassa is the prominent lake and it is affected by pollutants from point sources released from industries and service rendering centers and diffuse sources like intensive agriculture on the catchment (Abayneh et al., 2003, Zinabu, 2002).

Due to lack of intensive research in the rift valley lakes (Zinabu, 2002), the water quality of the lake and its impact on the lake ecosystems are not well addressed to use the water resources for various purposes like drinking, irrigation, aquatic life and recreational uses as their requirement.

Therefore, in this study an attempt was made to avail such basic information useful for the identification of water quality parameters for numerous purposes effectively and efficiently in Lake Hawassa and to indicate constraints of sustainability. The trophic status of the water and major nutrients which influences the sound ecosystem of the Lake would be assessed and estimated to evaluate the major sources in order to take appropriate actions. The specific objectives of the study were:

- to evaluate water quality parameters for drinking, irrigation, livestock, recreation and aquatic life against standards of WHO, USEPA, FAO, and CCEM guidelines
- to determine the trophic state index of the lake

2. MATERIALS AND METHODS

Lake Hawassa (Figure 1) lies to the west of Hawassa town, the capital of the Southern Nation Nationalities and Peoples' Regional State. The study site is situated 275km south of Addis Ababa and located between 06º 58´– 07º 14´ N latitudes and 38º 22´–38 º 28´ E longitudes, and at altitude of 1685m above sea level (m.a.s.l). The area receives a mean annual rainfall of 950mm and has a mean annual air temperature of 19.8°C.

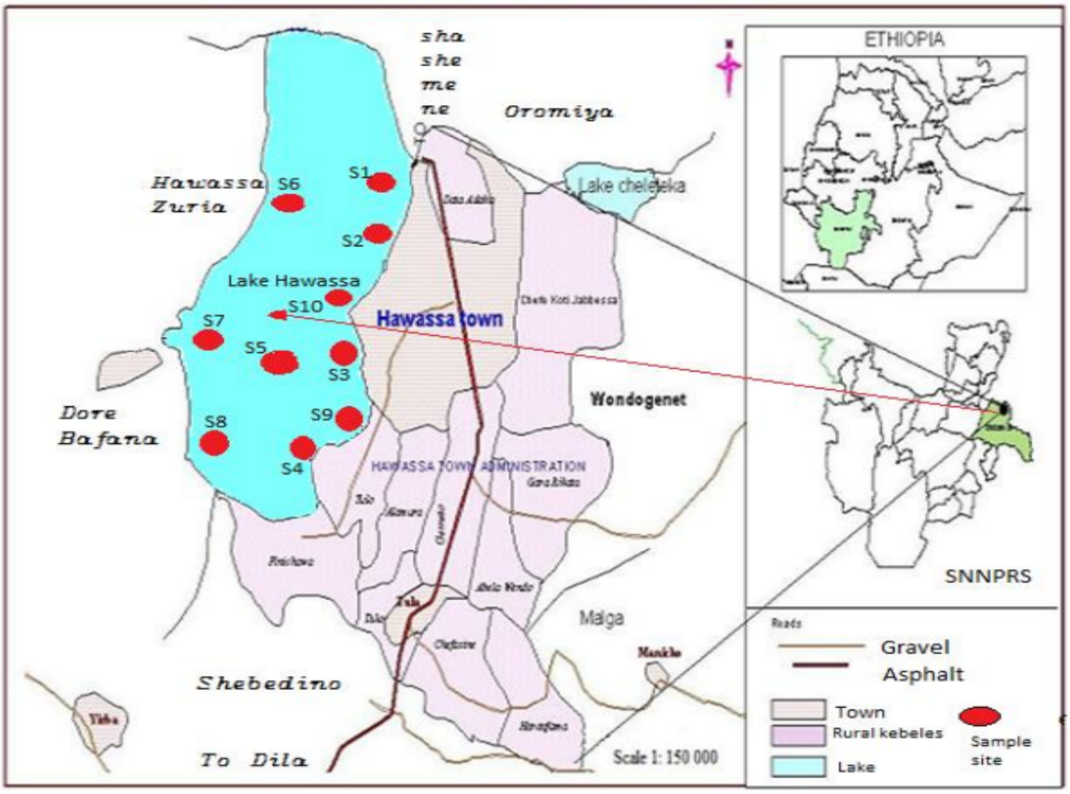

Figure 1. Location map of the study area and sampling sites on the Lake Hawassa

The drainage basin (catchment) area of the lake is 1250km^2 with the shoreline length from 50-65km and the surface area of the Lake is around 94km^2 (Girma and Ahlgren, 2009). The average annual inflow and outflow from the Lake Hawassa is 1440mm and 570mm (underground flow), respectively (Arkady and Brook, 2008). The maximum depth of the lake is 22m and the mean depth of 11m (Elias, 2000). Evaporation from the Lake Hawassa is estimated to be 1710mm/year (Gugissa, 2004) and the total volume of the lake water is 1.3km^3 (Tenalem, 1998).

The choices of sampling stations were based on the various uses of the lake water and their location, relative magnitude and importance. The study was conducted from December up to February, 2011/12. There is no seasonal variation in sampling period but by considering the site in lake more influenced by human activities in order to compare with an ideal places (taking sample from the center area and areas with minimum disturbance on the opposite site to the town). Ten study sites were selected and sampled to study the lake water quality assessment, which is presented in Table 1 and on Figure 1.

Table 1. Sampling sites on Lake Hawassa

Code name	Site name	Altitude (m)	Latitude	Longitude
S1	Inlet of Tikurwuha river	1688	035°28.867'	07°05.363'
S2	Haile resort area	1684	038°28.645'	07°04.776'
S3	Lewi resort area	1683	038°27.569'	07°02.988'
S4	Referal hospital area	1688	038°27.543'	07°01.544'
S5	Center of the lake	1685	038°27.100'	07°02.793'
S6	Direct opposite to Haile resort	1687	038°25.597'	07°05.625'
S7	Direct opposite to Lewi resort	1686	038°25.308'	07°03.954'
S8	Direct opposite to Referal hospital	1691	038°24.047'	07°01.412'
S9	Amora-Gedel	1655	038°27.408'	07°02.487'
S10	Recreational area ‘Yefikir Hayk’	1672	038°28.035'	07°03.293'
	Average to the lake	1685	038°27'	07°03'

One of the most common sources of error in water sample data collection is improper sampling, thus representative samples both in time and space will be required. Systematic sampling method and random sampling method were employed (AWWA, 1982; Cressie, 1993). In this sampling method, a random starting point was selected and samples were taken in one month interval. The samples for all parameters were collected at the same day from the surface and 1m from the depth of the lake to achieve consistency in sampling and evaluate depth variation. Hence a total of thirty samples were collected in field duplicate (twice) from the surface (from about 30 cm depths) and depth of the lake (using depth samplers), totally sixty samples.

Following data collection, the samples were carefully transported using an ice Box to the Applied Microbiology Laboratory (for bacteriological analysis) and Applied Chemistry Laboratory of Hawassa University (for physicochemical analysis).

All parameters were determined according to the standard methods (APHA, 1998) unless and otherwise stated. The samples were filtered using Whatman's No 42 filter paper and stored at 4^{o}C until analysis was carried out except sample for bacteriological and chlorophyll-a (chll-a) analysis. Temperature, EC, TDS, salinity and pH measure were taken immediately after the sample transported to laboratory by using pH and conductivity meter (HANNA pH211, microprocessor pH meter).

Results of water analysis were compared against WHO, USEPA, FAO, CCEM and other national and international standards. Analysis of variance (ANOVA) at 5% level of significance was used to compare the quality of water among all sites by Tukey-Kramer test. The results were analyzed by descriptive and multivariate analysis (MANOVA) using statistical software SPSS version 17 and Microsoft Excel.

Table 2. Standard water quality parameters determination methods and instruments used

Parameters	Determination method and instrument
Temp.,EC, TDS&salinity	pH and Conductivity meter (HANNA pH211)
BOD_5&DO	Modified Winkler-Azide dilution technique
Turbidity	Nephelometeric (HACH, model 2100A)
Secchi depth	20cm Secchi disk
NO_3^-, NO_2^-, PO_4^{3-}, NH_3&NH_4^+	Photometric measurements using flame photometer
Chloride	Mohr Agregetrometric titration method
Fluoride	Spectrophotometerically by Ampule method (HACH, Model 41100-21)
COD	Determined by dichromate reflux method through oxidation of the sample with potassium dichromate in sulphuric acid solution followed by titration
Mg, Na, K, Ca, Cr, Cd, Cu, Mn, Zn&Pb	Determined by atomic absorption spectrometer, AASP (Varian SP-20) using their respective standard hollow cathode lamps (APHA, AWWA, 1995).
Iron	Determined by using UNICAM UV-300 thermo electrode.
TC&FC	Most probable number method (MPN/100ml)
Chlorophyll-a	Spectrophotometerically (APHA, AWWA and WPCF, 1998).
Indices (SAR, MAR, SSP, KR&TH)	Richards (1954); Raghunath, (1987); Todd(1980); and Kelly’s,(1963) empirical formulas

3. RESULTS AND DISCUSSION

3.1 Physicochemical and Biological Characteristics of Lake Hawassa Water

3.1.1 Temperature and dissolved oxygen (DO)

The water temperature of Lake Hawassa varied between 20.98 and 21.33^{o}C with an average value of 21.23^{o}C to the lake system. The mean temperature of 20.56^{o}C, 21.07^{o}C and 22.05^{o}C for December, February and January, respectively, were recorded. There is a significant difference of the temperature value in site, month and depth ($P<0.05$). The temperature recorded for the February month in Lake Hora was 21.3^{o}C (Habiba, 2010) which is similar to the Lake Hawassa. Water temperature is a controlling factor for aquatic life (Carr and Neary, 2006). It controls the rate of metabolic activities, reproductive activities and life cycles. If water temperatures increase, decrease or fluctuate too widely, metabolic activities may speed up, slow down, malfunction, or stop altogether (Murdoch and Cheo, 1991).

The concentration of DO regulates the distribution of flora and fauna. The present investigation indicated that the concentration of DO fluctuated from 11.2mg/l (Inlet of Tikurwuha River) to 21.42mg/l (opposite to Lewi resort) with an average of 17.85mg/l to the lake system. An average value of 18.39mg/l, 11.69mg/l and 23.45mg/l for December, January and February, respectively and 18.03mg/l for surface and 17.66mg/l for the bottom of the Lake system has been obtained. The DO value registered in the Lake Hora agrees with the value obtained for Dec and Jan months of the Lake Hawassa, 16.7mg/l (Habiba, 2010). USEPA (1998) defined the healthy water value of DO within the range of 5-14.6mg/l and less 5 or greater than 14.6 indicates the impairment of the water body. According to this view the lake water having elevated DO level may show the pollution problem of the lake. The value of DO is within the permissible limits of EPA and WHO (1993) (>5mg/l) standard in all sampling sites for the drinking and aquatic life.

3.1.2 Chemical oxygen demand (COD) and biological oxygen demand (BOD_5)

The COD values of lake water samples ranged from 31.5(S7) to 80.5 mg/l (S8) with an average value of 48.73mg/l for the lake system. An average concentration of 49.23mg/l COD in surface and 48.23mg/l in the bottom, 35.9mg/l, 56mg/l and 54 mg/l of COD for December, January and February, respectively, were recorded in lake water. BOD_5 maximum mean value recorded in site S9 (this site is the inlet for overall town discharges and storm water), 157.67mg/l and the mean minimum was in site S2 (around Haile resort) 56.17mg/l with the total average value of 117mg/l to the lake. BOD is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions (Tenagne, 2009).The concentration of BOD_5 beyond the permissible limits of EPA guideline (<5mg/l) for aquatic organisms in all sites; which indicates the lake is highly polluted by the organic matters (Hino and Matswo, 1994; Clork, 1997). The present study result confirming with the previous result obtained by Alemayehu (2008) were COD (19.2mg/l) and BOD_5 (67.8mg/l) for the Lake Hawassa which means the value of BOD_5 is greater than COD. These all indicates the main pollution source to the lake is organic compounds or biologically degradable matters and the presence of high algae in the lake.

3.1.3 Electrical conductivity (EC) and total dissolved solids (TDS)

In all sampling sites, months and depths the EC, on average 750.1 µS/cm, value is in far below the WHO guideline value prescribed for drinking purpose (1500µS/cm) and EPA guideline (1000 µS/cm). The EC value was rated under excellent classes for all livestock and poultry watering purposes (FAO, 1985), i.e., <1000 µS/cm. The highest TDS value obtained in site S9, 455.6±0.124mg/l and at site S2, 454.67±0.124mg/l. The presence of high TDS in site S9 is due to the overall town discharges. The value of study agrees with the former research result registered by Yosef et al., (2010) for TDS (411mg/l) and Alemayehu (2008) 549mg/l for the Lake Hawassa.

Table 3. Average physicochemical analysis results of the lake by using Tukey-Kramer test (Mean, n=18)

Parameters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
EC	701.2a	756.8c	751.8b	757.5f	754.7c	755c	756.2d	755.7d	756.2d	756d
TDS	420.8a	454.7h	450.7b	454g	452.2c	453.2de	453.7fg	453d	455.6i	453.5ef
TSS	0.030i	0.027h	0.017d	0.017d	0.012a	0.017d	0.013b	0.015c	0.013b	0.023g
pH	6.98a	7.71e	7.58bc	7.73e	7.66d	7.54bc	7.58bc	7.54bc	7.53b	7.59c
Temp.	21.33c	20.98a	21.33c	21.25bc	21.17b	21.23bc	21.05a	21.25bc	21.33c	21.32c
DO	11.2a	17.37c	18.35e	17.78d	18.4e	19.17g	21.42i	20.55h	18.85f	15.4b
Turb.	20.98c	7.02a	6.98a	6.82a	6.95a	6.98a	6.93a	6.87a	6.92a	7.97b
COD	38.67c	46e	43c	32.17a	56.67f	39.83c	31.5a	80.5h	63.17g	55.83f
BOD5	94.5d	56.17a	73.33b	138.2g	92.17c	133.5e	143h	144.8i	157.7j	136.7f
COD/BOD5	0.388	0.819	0.586	0.233	0.615	0.298	0.220	0.556	0.401	0.408
F^-	2.31a	14.32g	11.83b	17.29j	14.45h	12.36c	15.65i	13.9f	13.27e	12.9d
Cl^-	31.31c	28.95a	31.91d	33.09e	28.95a	31.91d	28.9a	31.91d	31.31c	30.1b
TH	124.21e	106.07a	107.88b	126.97h	122.63d	125.29g	130.53i	124.72h	113.25c	137.16j

Note: *The analytical results were statistically significant at P<0.05. Values represent means of physicochemical parameters describing the water quality in the lake. Values with the same letter of superscripts are not significantly different (P<0.05). All units are in mg L^{-1} saving Temperature, Turbidity, EC, and pH which are expressed in °C, NTU, µS cm^{-1}, and unit less, respectively.*

3.2.4 Total hardness (TH), calcium (Ca) and magnesium (Mg)

The total hardness value in site variation shows the range from 106.07 (S2) to 137.16±0.136mg/l (at recreational area) with an average value of 121.87mg/l. All values of total hardness are within limits prescribed by WHO (1984) for the drinking water purposes, (<500mg/l).

Principally, the Ca and Mg presence are responsible for the hardness of the water and their desirable limits are 75–200mg/l and 30–100mg/l, respectively. In this study, the observed values for Ca were 2.34–2.92mg/l with an average of 2.56mg/l and those for Mg ranges from 24.25–31.92mg/l with an average value of 28.07mg/l. Very high magnesium imparts an unpleasant taste to the potable water (Piska, 2000), but in the current study the concentration was far below the recommended value by WHO (1984).

3.1.5 Sodium (Na) and potassium (K)

The content of Na in lake water samples ranged 300.95mg/l to 414.11mg/l with an average value of 331.14mg/l. In all the sampled sites the concentration of Na is higher than permissible limit of WHO (1984) (200mg/l). A higher sodium intake may cause hypertension, congenial heart diseases and kidney problems (Singh et al., 2008). So, with respect to Na content, the lake water is not suitable for the drinking purposes. Increased concentrations in surface waters may also arise from sewage and industrial effluents (Chin, 2006).

The average potassium value for the lake water sample ranges from 70.54(S6) to 85.04mg/l, S4, (around Referral Hospital) (Table 4). That indicates the effect of hospital effluent discharge on the lake ecosystem. In the present study both K+ and Na+ were beyond the prescribed permissible allowable limits of WHO (1984), which is 20mg/l for K and 200mg/l for Na.

3.1.6 Chloride (Cl^-) and flouride (F^-)

The presence of chloride and fluoride in water in excess amounts is not desirable (WHO, 2004). In the present investigation, the concentration of Cl^- ranges between 28.95–33.09mg/l with an average value to the lake 30.84mg/l which is in far below the prescribed limits of WHO (1998), 250mg/l for drinking water. Its concentration above to that imparts water taste and may harm metallic pipes.

The most important source of fluoride in drinking-water is naturally occurring (WHO, 2004). The highest value of F^- (17.29mg/l) was registered in site S4 (Referral hospital area) and the minimum (2.31mg/l) in site S1 (inlet of Tikurwuha river). The total means of fluoride concentration in Lake Hawassa was 12.83±0.014mg/l, which is far apart from the recommended value of F^- concentration for the drinking water WHO(2006)(1.5mg/l) and EPA(3.0mg/l). This high value of fluoride indicates the high amount of fluoride in the ground and the runoff from areas where fluoride contained mineral present (Bedilu, 2005).

Concentrations in drinking water above the permissible limit (1.5mg/l) causes dental fluorisis. Continuous intake of 3mg/l to 6mg/l fluoride content water for a long period may leads to skeletal fluorisis, if these concentrations exceeded, crippling skeletal fluorisis occur (Kloos and Redda, 1999). Based on this fact the Lake Hawassa is not suitable for the drinking, irrigation, & livestock watering purposes (CCEM, 1999; WHO, 2006).

3.1.7 pH and turbidity

The pH of the lake water ranged from 6.98 to 7.71 with an average value of 7.54. High value of pH in February is due to the rainfall, which may dilute the alkaline substances or the dissolution of the atmospheric carbon dioxide (Sheikh Nisar and Yaregi, 2003). The value of pH decreased in the lake in comparing the previous researches done by Alemayehu (2008) (pH=8.5) and Elizabeth et al., (1994), i.e., 8.8 for the Lake Hawassa. These may reveal the increment of organic matter load to the lake ecosystem. The pH of the lake is within the permissible limits of (WHO, 2006; FDRE, MoWR, 2002; EPA, 2003) for drinking, recreation, agricultural and aquatic life water use (6.5-8.5/9).

The turbidity value ranged between 6.82 and 20.98 NTU with an average value of 8.44NTU. The turbidity of the lake water is higher than the permissible limit <5NTU WHO (1993), while WHO (2006) stated that drinking water is best consumed with NTU less than 1NTU for health purposes.

Table 4. Summary of basic and heavy metals analysis result of the lake water (Mean±SE, n=18). All measurement units are given in mg/l except stated.

Parameters (units)	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Fe	0.180g	0.071a	0.072ab	0.078e	0.073bc	0.075d	0.074c	0.072ab	0.078e	0.080f
Cu	0.046e	0.006b	0.005a	0.011d	0.005a	0.005a	0.005a	0.005a	0.005a	0.001c
Mn	0.489± 0.001f	0.056± 0.001e	0.039± 0.001b	0.043± 0.001c	0.036± 0.001a	0.034± 0.001a	0.056± 0.001e	0.052± 0.001d	0.043± 0.001c	0.040± 0.001b
Zn	0.32 e	0.31e	0.19c	0.16b	0.23d	0.17b	0.12a	0.12a	0.16b	0.16b
Mg^{2+}	28.54± 0.038e	24.25± 0.038a	24.67± 0.038b	29.24± 0.038h	28.29± 0.038d	28.93± 0.038g	29.96± 0.038i	28.81± 0.038f	26.08± 0.038c	31.92± 0.038j
Mg^{2+} (meq/l)	2.35± 0.003	1.99± 0.003	2.03± 0.003	2.41± 0.003	2.33± 0.003	2.38± 0.003	2.46± 0.003	2.37± 0.003	2.15± 0.003	2.63± 0.003
Ca^{2+} (mg/l)	2.72± 0.013g	2.53± 0.013de	2.55± 0.013e	2.68± 0.013f	2.49± 0.013cd	2.51± 0.013cde	2.92± 0.013h	2.48± 0.013c	2.39± 0.013b	2.34± 0.013a
Ca^{2+} (meq/l)	0.136± 0.001	0.126± 0.001	0.127± 0.001	0.134± 0.001	0.124± 0.001	0.125± 0.001	0.145± 0.001	0.124± 0.001	0.119± 0.001	0.117± 0.001
K^+ (mg/l)	71.82± 0.057e	75.18± 0.057h	70.80± 0.057c	85.04± 0.057j	74.87± 0.057g	70.54± 0.057b	69.46± 0.057a	78.71± 0.057i	71.39± 0.057d	72.76± 0.057f
K^+ (meq/l)	1.84± 0.001	1.92± 0.001	1.81± 0.001	2.18± 0.001	1.92± 0.001	1.80± 0.001	1.78± 0.001	2.01± 0.001	1.83± 0.001	1.86± 0.001
Na^+ (mg/l)	300.95± 0.095a	341.61± 0.095h	301.25± 0.095b	348.83± 0.095i	325.55± 0.095g	324.08± 0.095f	414.11± 0.095j	317.55± 0.095d	315.56± 0.095c	321.87± 0.095e
Na^+ (meq)	13.09	14.86	13.10	15.17	14.16	14.10	18.01	13.81	13.73	14.00

***Note**: The analytical results were statistically significant at P<0.05. Values represent means of physicochemical parameters describing the water quality in the lake. Values with the same letter of superscripts are not significantly different (P<0.05).*

3.1.8 Nitrate-nitrogen (NO_3–N), Nitrite-Nitrogen (NO_2–N) and phosphate (PO_4^{3-}P)

The highest mean value of 8.87±0.02mg/l (around Haile Resort) and 8.46±0.02mg/l (Referral hospital) nitrate were obtained in the lake with an average value of 5.271±0.006mg/l to the lake system. In all observed sites the amounts of nitrate concentration at lake were by far below the permissible limit of WHO (2004) for drinking aspects which is 10mg/l. Excess nitrate in drinking water causes infantile methaemoglobinaemia, which acts on hemoglobin in children, leading to poor oxygen uptake at the cellular level (WHO, 1984). According to Murdoch et al., (2001), high nitrate content (>1mg/l) is not conducive for aquatic life. Nonetheless, in unpolluted waters the level of nitrate-nitrogen is usually less than 0.1mg/l (Chapman, 1996). But the value obtained in the present study may indicate the great pollution of the lake by the nutrient.

The nitrite values for the three months were 0.052±0.007mg/l, 0.031±0.007mg/l and 0.029±0.007mg/l, December, January and February, respectively, registered. In this study the concentration of nitrite was found in small amount in all sampled sites and to some extent increased in the Inlet of Tikurwuha River (0.103mg/l). These may be due to organic wastes, agricultural fertilizers, intensive livestock operations, surface runoff, sewage discharge and atmospheric deposition (WHO, 2004) into the lake through the river. In the normal status the lake nitrite level never goes greater than 0.001mg/l (Chapman and Kimstach, 1992), however, in the Lake Hawassa it reaches to 0.103mg/l.

The highest phosphate concentration observed at recreational area (1.415±0.008mg/l) and inlet of Tikurwuha river (1.362±0.008mg/l) (Table 4), this is due to the use of detergents and soaps to wash their clothes and for bathing as well as discharges of storm water and wastewater directly entering into the lake system. Based on the current value obtained, Lake Hawassa was highly polluted by phosphate and reaches to hypereutrophic level. It's above the maximum permissible limits according to WHO (1984) and EPA (2003) that may ranges from 0.005-0.02mg/l in surface water for different purposes and the healthiness of the water ecosystem.

Table 5. Analysis result of nutrients and biological parameters values of the lake water (Mean±SE,n=18)

Para-meters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
NO_3^-	3.02± 0.017a	8.87± 0.017j	6.29± 0.017h	8.46± 0.017i	5.26± 0.017g	4.47± 0.017d	3.84± 0.017c	3.30± 0.017b	4.64± 0.017f	4.54± 0.017e
PO_4^{-3}	1.36± 0.008g	1.11± 0.008d	0.98± 0.008b	1.07± 0.008c	1.15± 0.008e	0.99± 0.008b	0.97± 0.008b	0.85± 0.008a	1.28± 0.008f	1.42± 0.008h
NO_2^-	0.103± 0.014b	0.033± 0.014a	0.054± 0.014a	0.025± 0.014a	0.032± 0.014a	0.027± 0.014a	0.028± 0.014a	0.021± 0.014a	0.024± 0.014a	0.026± 0.014a
TN	3.08± 0.351a	8.91± 0.351e	6.35± 0.351d	8.49± 0.351e	5.29± 0.351cd	5.61± 0.351cd	3.87± 0.351ab	3.32± 0.351a	4.67± 0.351bc	4.57± 0.351bc
TP	0.449± 0.001i	0.367± 0.001f	0.325± 0.001c	0.354± 0.001e	0.378± 0.001g	0.328± 0.001d	0.320± 0.001b	0.281± 0.001a	0.424± 0.001h	0.509± 0.001j
TN/TP	6.79± 0.029a	24.87± 0.029j	19.16± 0.029h	23.87± 0.029i	13.67± 0.029f	14.72± 0.029g	12.30± 0.029d	12.62± 0.029e	10.99± 0.029c	10.76± 0.029b
Chll-a	27.885± 0.05h	28.352± 0.05i	36.640± 0.05j	24.085± 0.05b	24.465± 0.05f	23.192± 0.05d	22.847± 0.05c	19.372± 0.05a	21.545± 0.05b	26.087± 0.05g

***Note**: The analytical results were statistically significant at P<0.05. Values represent means of physicochemical and biological parameters describing the water quality in the lake. Values with the same letter of superscripts are not significantly different (P<0.05). All units are given in mg/L except chlla which is in µg/L*

3.2 Bacteriological characteristics of Lake Hawassa water

The result of this analysis for total coliform bacteria ranges from 6,000MPN/100ml (at site S6) to 20833.33MPN/100ml (at site S10) with an average of 11,883MPN/100ml which indicates the presence of high contamination. In all areas the value is beyond the recommended total coliform concentration of the maximum permissible limits of WHO (2006), and EU (1998), zero/100ml for the drinking, irrigation and recreational uses. The value of total coilform is beyond the acceptable limits for irrigation water use (CCME, 1999) and WHO (1989), 1,000MPN/100ml in all sampled sites. The total coliform of the lake water (11,883MPN/100ml) is beyond the acceptable limit of WHO (1983) and CCME (1999) standards (<1000MPN/100ml) for untreated freshwater used for unrestricted irrigation of row consumed crops as well as fishing. Based on this fact the lake water was highly contaminated by bacteriological aspects and it does not fit for irrigation, drinking, recreation and fishing purposes. The fecal coliform count of the lake was above the recommended limits of the shellfish harvesting water, i.e., 14MPN/100ml as a guideline of USEPA (1976).

Table 6. Average bacteriological water quality analysis results (Mean, n=18)

Para-meters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
TC	12,333.33g	15,833.33i	12,166.67f	9,500c	12,833.33h	6,000a	8,666.67b	10,666.67e	10,000d	20,833.33j
FC	213.3j	130h	63.33c	78.3e	46.67a	66.67d	58.33b	85f	91.7g	163.33i

***Note:** TC and FC units in MPN/100ml. The analytical results were statistically significant at P<0.05. Values represent means of bacteriological parameters describing the water quality in the lake. Values with the same letter of superscripts are not significantly different (P<0.05).*

3.3 Irrigation Water Quality Assessment

3.3.1 Total salinity (TDS/EC)

Salts of calcium, magnesium, sodium, and potassium were present in the irrigation water may prove to be injurious to plants. The values of TDS at the entire sampled site are below 1,000mg/l and they are considered to be excellent for irrigation purposes according to Robinove et al., (1958).

The TDS of the Lake Hawassa (455.6mg/l) were comparable with the Lake Ziway which ranges from 200 to 400mg/l (Hengsdijk and Jansen, 2006). But the TDS value is far less than the other rift valley lakes like Abaya and Chamo with the value of 911.10mg/l and 1522.45mg/l, respectively.

The EC value of Lake Hawassa is less than the EC value of all rift valley lakes except Lake Ziway (Tenalem, 1998). This indicates that all rift valley lakes contain high levels of ions than Lake Hawassa and Ziway (Zenebe et al., 1998).

3.3.2 Sodium adsorption ratio (SAR), SSP, KR and MAR

The SAR value obtained in the present study ranged from 12.195meq/l (at inlet of Tikurwuha river) to 16.008meq/l (at opposite to Lewi resort), with an average value of 13.37±0.002meq/l for the lake system. According to the standard presented by Ayers and Westcot (1985) and Richards (1954), the result obtained falls under the category C2S2 (Tables 7 and 8). That means the result indicating medium alkali hazards and good irrigation water (US Salinity Laboratory Staff, 1954).

Table 7. Limits of some parameter indices for rating water quality and its sustainability in irrigation (Ayers and Westcot, 1985; Eaton, 1950; Wilcox, 1950; Todd, 1980)

Category	EC(μS/cm)	RSC(meq/l)	SAR	SSP (%)	Sustainability for Irrigation
I	<117.509	<1.25	<10	<20	Excellent
II	117.509-508.61	1.25-2.5	10-18	20-40	Good
III	>508.61	>2.5	16-26	40-80	Fair
IV	_	_	>26	>80	Poor

The current value of SSP ranged from 83.8% (at S10) to 84.3% (at S2) with an average value of 86% to the lake system. The value obtained was above the acceptable limits (Wilcox, 1955) for the irrigation water use. High percentage of sodium on irrigation water may stunt the plant growth, deflocculation and reduces the soil permeability (Joshi *et al*., 2009; Singh *et al*., 2008).

The analyzed water results of the MAR value ranged between 93.84% (S2) and 95.37% (S10) with an average value of 94.5%, which indicating they are above the acceptable limit of 50% (Ayers and Westcost, 1985). The waters are, therefore, considered unsuitable. If the proportion of Mg_2^+:Ca_2^+ ratio was greater than 4:1 (in the present study the value was greater than 10:1), the problem of structural stability and tilth conditions may happen which impedes the infiltration capacity of the soil (Micheal, 1987).

Table 8. Richard's classification of water for irrigation use based on SAR and EC value (Richard, 1954)

Water class	SAR	Index	EC(μS/cm)	Index
Excellent	≤10	S1	100–250	C1
Good	10–18	S2	250–750	C2
Fair	18–26	S3	750–2250	C3
Poor	≥26	S4	≥2250	C4

Based on this fact the investigation of the lake water was in category class II or good for irrigation aspects. The present study value of KR to the lake ranged between 5.71meq/l at site S10 and 7.18meq/l at site S7 with an average value of 6.27. These values indicates that the KR of lake water is far above than the recommended limit of 1.0 (Kelley, 1963) and are considered to be unsuitable for irrigation purposes. This was occurred due to the poor balance of Na^+ with Ca^{2+} and K^+ in the lake water. This condition may cause poor tilth of the soil with great permeability problem.

3.3.3 Major cations and anions in water

The sodium content of the lake water samples ranged 13.09 (at site S1) to 18.01meq/l (at site S7) with an average value of 14.4meq/l. The obtained value is far above the recommended limits for irrigation use (WHO, 1983 and UCCC, 1974), but within the range according to Ayers and Westcot (1985), i.e. 0-40meq/l. When the Na:Ca ratios exceeds 3:1(FAO, 1985), the soil will face with infiltration problem and using this lake water for the irrigation purposes may cause the soil dispersion, crusting, plugging and sealing of the surface pores since Na:Ca ratio is 14:1 (lake water concentration ratio) in average.

The value of Ca in the lake is in average 0.128meq/l which was below recommended limit (Richards, 1954). As the Ca ions are the best counter balance for the Na ion concentration, the amount was very low to neutralize the Na content related effects, permeability problem. The magnesium content obtained on the study area ranges from 1.99meq/l to 2.63meq/l with an average value of 2.31meq/l which is within the recommended limits (Ayers and Westcot, 1985).

The major anions detected on this study were chloride that ranges from 0.815meq/l to 0.932meq/l with an average value of 0.87meq/l and the values were far below the recommended limits (CCME, 1999 and Ayers and Westcot, 1985). According to the CCME (1999) and WHO (1983), 1mg/l, fluoride content in the lake water (12.8mg/l) is more than twelve times greater than the recommended limits for the irrigation uses.

3.4 Recreational Water Quality Analysis of the Lake

An average total coliform count of the Lake Hawassa was 11,883MPN/100ml which is above the recommended limits of WHO (1989), BSI (2003) and CCME (1999) for the recreational purposes (<500 MPN/100ml) and the fecal coliform values also same to TC which is above the limit. The total coliform count of the lake is also greater than the mean total coliform count of Lake Babogaya (117.8±24.3MPN/100ml) and Lake Hora (73.2±7.6MPN/100ml) (Tewodros, 2008). This might be due to the subjectivity of Lake Hawassa to different sources of contamination.

Regarding to the clarity of the lake water, it is below the recommended limits of (CCME, 1999), i.e., Secchi depth value of 1.2m but the average value of the Lake Hawassa on this investigation was 0.65m. The transparency of water is highly required to safe recreation in water while the value of turbidity on this study is greater than the recommended limits (CCME, 1999) (<5NTU); 8.44NTU for the lake. Maintaining the clarity of the lake is very important for aesthetic, economic, public health and ecological reasons. Based on the above results the lake is not suitable for direct and indirect or primary and secondary recreation.

3.5 Trophic State Index (TSI) of the Lake Hawassa

The trophic state indices calculated for the Lake Hawassa water were: TSI(Chlla) 59.68–65.93, TSI(TP) 85.46–94.04, TSI(TN) 70.68–86.01 and TSI(SD) 64.14–70.13. The Carlson's average TSI value for the lake was 72.6 that indicate the lake is at a hypereutrophic level (Table 9). The main factor which elevates the trophic states was the total phosphorus concentration in the lake, but the other two parameters are within the range of eutrophic level (Carlson, 1977).

Typically, phosphorus is the single best chemical indicator of the condition of a nutrient-rich lake. Algae need as little as 0.02mg/l of phosphorus to cause a nuisance algal bloom (Wetzel, 1983). The average concentration of total phosphorus (TP) during the study period was ranged from 0.281mg/l at site S8 to 0.509mg/l at the site S10 with an average value of 0.369mg/l to the whole lake system. The overall phosphorus concentration greater than 300μg/l (US EPA, 2005) shows the lake was most-disturbed by anthropogenic factors. Based on this fact the lake water was highly impaired with the concentration of the phosphorus nutrient.

According to EPA (2003) the level of total nitrogen in water above 1.1mg/l indicates the most-disturbances of the aquatic body by the nutrient through human induced action, but the lake water TN is in average 5.42mg/l which refers impairment of the lake. The great accumulations of nutrients in the Lake Hawassa were due to the absence of nutrients outputs or export from the lake ecosystem; because it's closed basin lake (Calgary, 2005).

The nutrient limitation was estimated by using the ratio of TN:TP in the lake water and it's directly related with the biomass concentration of the water or tells the nutrient enrichment source and effective polluting factors in the ecosystem. The average TN:TP ratio for the water samples collected from the Lake Hawassa ranged from 6.79 (at inlet of Tikurwuha river) to 24.87(at Haile resort area) with an average value of 14.98 (Table 9). The ideal ratio of nitrogen to phosphorus ratio for aquatic plant growth is 10:1. Ratios higher than 10 indicates a phosphorus-limited system. Those that are less than 10:1 represent nitrogen-limited systems. Based on this category the Lake Hawassa was phosphorus limited in all sampling points, except S1. So, taking great measure on phosphorus releasing sources is very essential to maintain the lake ecosystem from nuisance eutrophication process.

Table 9. Carlson's Trophic State Index for the Lake Hawassa

Site of sampling	*Means of components*					*Trophic state index by each*				*TSI of the lake*	*TSI of Lake*
	TP(µg/l)	*Chlla(µg/l)*	*SD(m)*	*TN(mg/l)*	*TN:TP*	*TSI_TP*	*TSI_Chlla*	*TSI_SD*	*TSI_TN*		
S1	*449.3*	*27.885*	*0.495*	*3.08*	*6.792*	*92.21*	*63.25*	*70.13*	*70.68*	*75.20*	*74.06*
S2	*366.8*	*28.352*	*0.625*	*8.91*	*24.87*	*89.3*	*63.41*	*66.77*	*86.01*	*73.16*	*76.37*
S3	*324.5*	*36.640*	*0.665*	*6.35*	*19.16*	*87.53*	*65.93*	*65.87*	*81.12*	*73.11*	*75.11*
S4	*353.9*	*24.085*	*0.675*	*8.49*	*23.87*	*88.78*	*61.81*	*65.66*	*85.31*	*72.08*	*75.39*
S5	*378.4*	*24.465*	*0.660*	*5.29*	*13.67*	*89.75*	*61.91*	*65.98*	*78.49*	*72.56*	*74.03*
S6	*327.7*	*23.192*	*0.750*	*5.61*	*14.72*	*87.67*	*61.44*	*64.14*	*79.34*	*71.08*	*73.15*
S7	*319.5*	*22.847*	*0.675*	*3.87*	*12.30*	*87.31*	*61.29*	*65.66*	*73.98*	*71.42*	*72.06*
S8	*281.1*	*19.372*	*0.680*	*3.32*	*12.62*	*85.46*	*59.68*	*65.55*	*71.76*	*70.23*	*70.61*
S9	*424.1*	*21.545*	*0.660*	*4.67*	*10.99*	*91.39*	*60.72*	*65.98*	*76.69*	*72.70*	*73.70*
S10	*509.6*	*26.110*	*0.635*	*4.57*	*10.76*	*94.04*	*62.60*	*66.54*	*76.38*	*74.39*	*74.89*
Overall total trophic state index of the Lake Hawassa										*72.59*	*73.94*

***Note**: The bold one indicates the total nitrogen as component for the TSI determination; including TSI_TN.*

The concentration of chlorophyll-a ranged between 19.37µg/l and 36.64µg/l with an average lake water concentration of 25.45µg/l. The increase in the mean chlorophyll-a concentration from 18.4 µg/l (Girma and Ahlgren, 2009) to 36.64 µg/l (in the present study) may show an increase in the productivity of the lake that can be attributed to human activities in the watershed. The value recorded for the Lake Hora was ranged within 19.1-47.6µg/l (Abebaw, 2007) which agrees with the current study value (19.37-36.64 µg/l).

The Lake Hawassa had low transparency throughout the whole sampling site ranged from 0.495 to 0.75m and, therefore, is generally regarded as a productive lake. As Thornton (1986) stated the trophic state of the lake based on the phytoplankton biomass measured as chlorophyll-a concentration, 40, 20 and 31µg/l for Lake Ziway, Hawassa and Chamo, respectively, were considered as eutrophic state. The state of eutrophication increased from eutrophic to hypereutrophic state in the current study after 26 years for the Lake Hawassa (Thornton, 1986; Girma and Ahlgren, 2009).

3.6 Heavy Metals Analysis for the intended uses

Trace levels of dissolved metals in surface water are essential for proper biological functioning. Many are important in basic physiological functions in both plants and animals, as blood components or cofactors in enzyme reactions (CCME 1987). The maximum average concentration values were registered in the Inlet of Tikurwuha River for Zn (0.317mg/l), Fe (0.18mg/l), Cu (0.046mg/l) and Mn (0.489mg/l). This is due to the impact of factories which releases the heavy metals into Tikurwuha River, like Hawassa Textile factory (Yosef et al., 2010). In all sampled points the Cr, Cd, Ni & Pb were non-detectable; these make the lake water suitable for aquatic life like fish. The study value of heavy metals results agrees with the former investigation of Lake Hawassa done by Zinabu and Pearce (2003). Based on the result obtained for heavy metals, the lake water is suitable for drinking, irrigation and aquatic uses (USEPA, 1998; WHO, 1993 and 1998).

4. CONCLUSIONS AND RECOMMENDATION

Based on the physicochemical and biological water quality characteristics the lake water was unsuitable for drinking/domestic uses without treatment. These were due to the great impairment of the water with F^-(12.8mg/l), Na(331.14mg/l), BOD(117mg/l), COD(48.73mg/l), K(70mg/l) and bacteriological parameters like TC (11,883MPN/100ml) and FC (99.69MPN/100ml) which were above the recommended standard values of WHO, USEPA,& EU. The elevated concentrations of bacteriological parameters and low clarity of the lake makes unsuitable for recreational uses.

Due to the great concentration of sodium ions, the SAR value was elevated in the lake water. According to various guidelines the suitability range of SAR to the lake need a great care to irrigate different crops in various soil conditions. The water quality parameters evaluated to observe the ability of the lake to sustain the aquatic life revealed that it's in good status. As the Carlson's trophic state index category the lake was found in Hypereutrophic status. The main factor for the eutrophication was TP and TN loading.

In general, the lake water is highly contaminated and may not fit for drinking and recreational uses but with some great care it is good for irrigation and aquatic life. So, the municipal administration and other service rendering sectors should provide the wastewater treatment plants in order to reduce the pollutants entering into the lake.

Further research should be conducted in the Lake Hawassa to investigate the detail water quality status of the lake by considering the seasonal/temporal (four seasons) variations of the water quality parameters throughout the year because the current research is only limited to dry season.

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