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PHYSICOCHEMICAL AND BIOLOGICAL 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 is situated in southern regional state, which has a closed basin system and receives water from only Tikurwuha River and runoff from the catchment. Quality of the 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 using 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 (7.5), TDS (450.1), temp.(21.23°C), DO (17.85), turbidity (8.44 NTU), COD (48.73), BOD5 (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), Chlorophyll-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 is suitable for aquatic life.

Keywords: Aquatic life, drinking, irrigation, Lake Hawassa, recreational, trophic state index, water quality parameters, water quality

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INTRODUCTION

Water is the elixir of life, a valuable gift of nature to mankind and millions of other species living on the earth (Chidambaram *et al.*, 2010). It is available in the world in huge quantity in the order of 1400 × 10^6 km^3, but only 41 000 km^3 circulates through the hydrological cycle, the remaining being stored for long periods in the oceans, ice caps and aquifers and only 3% of the waters in the world are fresh water (Acreman, 1998). Among the fresh waters, only about 5% of them or 0.15% of the total world waters are readily available for beneficial use (Sandeep *et al.*, 2011; Chidambaram *et al.*, 2010) and from these lakes hold 100 000 km^3 of freshwater (90%) of earth's liquid surface total water. Ethiopia has 199.3 BCM potential surface water and 185.6 BCM (billion cubic meters) groundwater as a reserve (Tamiru, 2006).

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 (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 above 0.4 (World Bank, 1992).

The quality of water is highly imperative component to understand the healthiness of a water body and it is a critical factor affecting human health and welfare (Al-Gahwari, 2007). Studies showed that approximately 3.1% of deaths (1.7 million) and 3.7% of disability-adjusted-life-years (DALYs) (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 & 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 sub-saharan 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 which are released from industries and service rendering centers and diffuse sources like intensive agriculture on the catchment (Ataro *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 analyze the quality of the lake water for physicochemical parameters
- to analyze the bacteriological/biological quality status of the lake
- to evaluate spatial variability in water quality parameters
- 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

MATERIALS AND METHODS

Lake Hawassa lies to the west of Hawassa town, the capital of the Southern Nation Nationalities and Peoples' Regional State. The study site is situated 275 km south of Addis Ababa and located between 06º58′–07º14′ N latitudes and 38º22′–38º28′ E longitudes, and at altitude of 1685 m.a.s.l. The area receives a mean annual rainfall of 950 mm and has a mean annual air temperature of 19.8°C. The area is characterized by three main seasons which are long rainy season (locally called Kiremt) in the summer from June-September (mean annual total rainfall accounts from 50-70%), dry period (locally called Bega) extends between October and February and small rain season (locally called Belg) during March and May when about 20−30% of the annual rainfall falls. Mean monthly rainfall is above 100 mm from April to September with August showing the highest 124 mm and the lowest rainfall occur in November, December and January (Halcrow, 2010).

The drainage basin (catchment) area of the lake is 1250 km^2 with the shoreline length from 50-65 km and the surface area of the Lake around 94 km^2 (Girma and Ahlgren, 2009). The average annual inflow and outflow from the Lake Hawassa is 1440 mm and 570 mm (underground flow), respectively (Deganovsky & Abate, 2008). There are no rivers to the west or north of the lake but from the eastern highlands or hills there is

Table 1. Sampling sites on Lake Hawassa

Codename	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 perennial river which fed by Wesha and Butra rivers near Wonde Genet that drains through Tikurwuha river to Lake Hawassa with mean monthly flow rate of 6−7 m^3/s with only slight seasonal variation (Halcrow, 2010). The maximum depth of the lake is 22 m and the mean depth of 11m (Dadebo, 2000).Evaporation from the Lake Hawassa is estimated to be 1710 mm/year (Gugissa, 2004) and the total volume of the lake water is 1.3 km^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 presented in **Table 1** and **Fig. 1**.

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). 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 (**Table 2**).

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°C until analysis was carried out except sample for bacteriological and chlorophyll-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 (ANOVA) using statistical software SPSS version 17 and Microsoft excel.

RESULTS AND DISCUSSION

Temperature and dissolved oxygen (DO)

The water temperature of Lake Hawassa varied between 20.98 and 21.33°C with an average value of 21.23°C to the lake system. The mean temperature of 20.56°C, 21.07°C and 22.05°C for December, February and January, respectively, were recorded. There is a significant difference of the temperature value in site, month and depth ($P<0.05$). Water temperature is a controlling factor for aquatic life (Carr & 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 *et al.*, 2001).

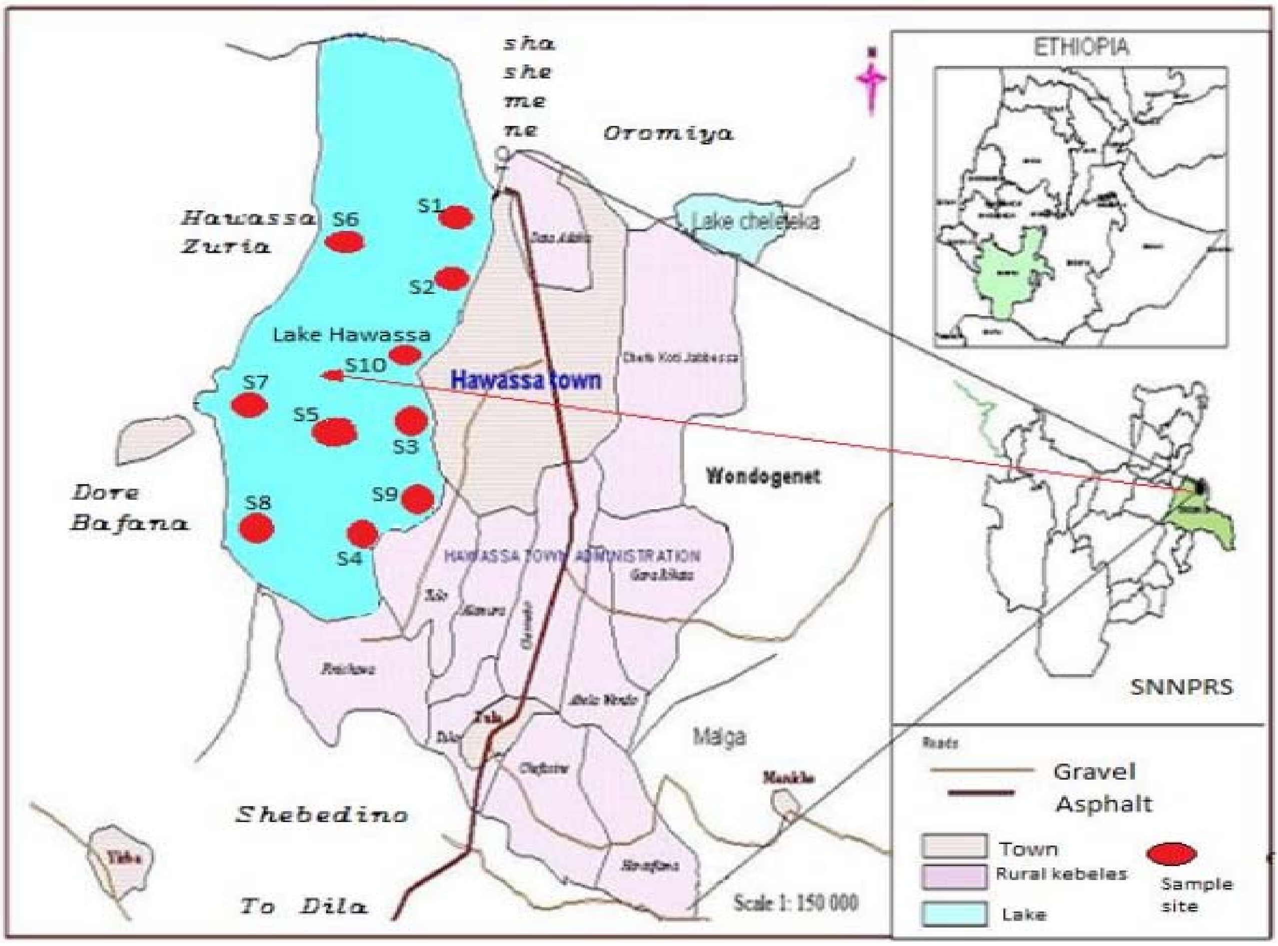

Fig.1 Location map of the study area and sampling sites on the Lake Hawassa.

Table2. 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 diameter of 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

The concentration of DO regulates the distribution of flora and fauna in the waterbody. The present investigation indicated that the concentration of DO fluctuated from 11.2 (S1) to 21.42 mg/L (S7) with an average of 17.85 mg/L to the lake system. An average value of 18.39 mg/L, 11.69 mg/L and 23.45 mg/L for December, January and February, respectively and 18.03 mg/l for surface and 17.66 mg/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 December and January months of the Lake Hawassa, 16.7 mg/L (Habiba, 2010). USEPA (1998) defined the healthy water value of DO within the range of 5−14.6 mg/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

(2004) (>5 mg/L) standard in all sampling sites for the drinking and aquatic life.

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

The COD values ranged from 31.5(S7) to 80.5 mg/L (S8) with an average value of 48.7 mg/l for the lake system. An average concentration of 49.2 mg/L COD in surface and 48.2 mg/L in the bottom, 35.9, 56 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), 157.7 mg/L and the mean minimum was in site S2, 56.2 mg/L with an average value of 117 mg/L to the lake (**Table 3**).

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 $BOD_5$is beyond the permissible limits of EPA guideline (<5 mg/L) for aquatic organisms in all sites; which indicates the lake is highly polluted by the organic matters. The present study result confirming with the previous result obtained by Alemayehu (2008) were COD (19.2 mg/L) and BOD_5 (67.8 mg/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.

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

In all sampling sites, months and depths the EC, in average 750.1 µS/cm, value is in far below the WHO guideline value prescribed for drinking purpose (1500 µS/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 mg/L and at site S2, 454.7 mg/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 Giorgis *et al.* (2010) for TDS (411mg/L) and Alemayehu (2008) 549 mg/L for the Lake Hawassa.

Total hardness (TH), calcium and magnesium

The total hardness value in site variation shows the range from 106.07 (S2) to 137.16 mg/L (S10) with an average value of 121.87 mg/L. All values of total hardness are within the limits prescribed by WHO for the drinking water purposes, (<500 mg/L).

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

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	701.2^{a}	756.8^{c}	751.8^{b}	757.5^{f}	754.7^{c}	755^{c}	756.2^{d}	755.7^{d}	756.2^{d}	756^{d}
TDS	420.8^{a}	454.7^{h}	450.7^{b}	454^{g}	452.2^{c}	453.2^{de}	453.7^{fg}	453^{d}	455.6^{i}	453.5^{ef}
TSS	0.030^{i}	0.027^{h}	0.017^{d}	0.017^{d}	0.012^{a}	0.017^{d}	0.013^{b}	0.015^{c}	0.013^{b}	0.023^{g}
pH	7.0^{a}	7.7^{e}	7.6^{bc}	7.7^{e}	7.7^{d}	7.5^{bc}	7.6^{bc}	7.5^{bc}	7.5^{b}	7.6^{c}
Temp.	21.33^{c}	20.98^{a}	21.33^{c}	21.25^{bc}	21.17^{b}	21.23^{bc}	21.05^{a}	21.25^{bc}	21.33^{c}	21.32^{c}
DO	11.2^{a}	17.37^{c}	18.35^{e}	17.78^{d}	18.4^{e}	19.17^{g}	21.42^{i}	20.55^{h}	18.85^{f}	15.4^{b}
Turb.	20.98^{c}	7.02^{a}	6.98^{a}	6.82^{a}	6.95^{a}	6.98^{a}	6.93^{a}	6.87^{a}	6.92^{a}	7.97^{b}
COD	38.67^{c}	46^{e}	43^{c}	32.17^{a}	56.67^{f}	39.83^{c}	31.5^{a}	80.5^{h}	63.17^{g}	55.83^{f}
BOD_5	94.5^{d}	56.2^{a}	73.3^{b}	138.2^{g}	92.2^{c}	133.5^{e}	143^{h}	144.8^{i}	157.7^{j}	136.7^{f}
COD/BOD_5	0.388	0.819	0.586	0.233	0.615	0.298	0.220	0.556	0.401	0.408
F^-	2.31^{a}	14.32^{g}	11.83^{b}	17.29^{j}	14.45^{h}	12.36^{c}	15.65^{i}	13.9^{f}	13.27^{e}	12.9^{d}
Cl^-	31.31^{c}	28.95^{a}	31.91^{d}	33.09^{e}	28.95^{a}	31.91^{d}	28.9^{a}	31.91^{d}	31.31^{c}	30.1^{b}
TH	124.21^{e}	106.07^{a}	107.88^{b}	126.97^{h}	122.63^{d}	125.29^{g}	130.53^{i}	124.72^{h}	113.25^{c}	137.16^{j}

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 non-dimensional, respectively.

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

Parameters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
	0.180 ± 0.038^{g}	0.071 ± 0.015^{a}	0.072 ± 0.010^{ab}	0.078 ± 0.015^{e}	0.073 ± 0.021^{bc}	0.075 ± 0.013^{d}	0.074 ± 0.017^{c}	0.072 ± 0.019^{ab}	0.078 ± 0.017^{e}	0.080 ± 0.016^{f}
Cu	0.046 ± 0.076^{e}	0.006 ± 0.007^{b}	0.005 ± 0.007^{a}	0.011 ± 0.008^{d}	0.005 ± 0.007^{a}	0.005 ± 0.007^{a}	0.005 ± 0.007^{a}	0.005 ± 0.007^{a}	0.005 ± 0.007^{a}	0.010 ± 0.007^{c}
Mn	0.489 ± 0.57^{f}	0.056 ± 0.020^{e}	0.039 ± 0.016^{b}	0.043 ± 0.010^{c}	0.036 ± 0.014^{a}	0.034 ± 0.015^{a}	0.056 ± 0.015^{e}	0.052 ± 0.013^{d}	0.043 ± 0.005^{c}	0.040 ± 0.018^{b}
Zn	0.317 ± 0.188^{e}	0.305 ± 0.207^{e}	0.188 ± 0.168^{c}	0.162 ± 0.097^{b}	0.234 ± 0.223^{d}	0.175 ± 0.123^{b}	0.116 ± 0.086^{a}	0.123 ± 0.092^{a}	0.162 ± 0.124^{b}	0.161 ± 0.094^{b}
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mg^{2+}	28.54 ± 7.47^{e}	24.25 ± 5.79^{a}	24.67 ± 4.57^{b}	29.24 ± 5.78^{h}	28.29 ± 6.83^{d}	28.93 ± 6.33^{g}	29.96 ± 6.31^{i}	28.81 ± 5.42^{f}	26.08 ± 4.24^{c}	31.92 ± 9.00^{j}
Ca^{2+}	2.72 ± 0.43^{g}	2.53 ± 0.27^{de}	2.55 ± 0.43^{e}	2.68 ± 0.45^{f}	2.49 ± 0.39^{cd}	2.51 ± 0.48^{cde}	2.92 ± 1.05^{h}	2.48 ± 0.40^{c}	2.39 ± 0.31^{b}	2.34 ± 0.35^{a}
K^{+}	71.82 ± 48.87^{e}	75.18 ± 33.38^{h}	70.80 ± 27.66^{c}	85.04 ± 35.75^{j}	74.87 ± 22.45^{g}	70.54 ± 22.84^{b}	69.46 ± 34.84^{a}	78.71 ± 26.41^{i}	71.39 ± 28.36^{d}	72.76 ± 29.79^{f}
Na^{+}	300.95 ± 112.31^{a}	341.61 ± 105.13^{h}	301.25 ± 81.37^{b}	348.83 ± 89.13^{i}	325.55 ± 75.78^{g}	324.08 ± 78.13^{f}	414.11 ± 177.77^{j}	317.55 ± 79.21^{d}	315.56 ± 80.44^{c}	321.87 ± 89.92^{e}

Note: ND refers to non-detectable. 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)

Sodium and potassium

The content of Na ranged 300.95 to 414.11 mg/L with an average value of 331.14 mg/L. In all the sampled sites the concentration of Na is higher than permissible limit of WHO (1984) (200 mg/L). More consumption of sodium may cause hypertension, congenial heart diseases and kidney problems (Singh *et al.*, 2008). According to Chin (2006) an elevated concentrations of Na in surface waters may arise from sewage and industrial effluents which directly joins lake water. An average potassium value for the lake water ranges from 70.54 (S6) to 85.04 mg/L (S4) (**Table 4**). In the present study both K^+ and Na^+ were beyond the prescribed permissible allowable limits of WHO (1984), which is 20 mg/L for K and 200 mg/L for Na.

Chloride and flouride

The existence of chloride and fluoride in water in excess amounts is not desirable (WHO, 2004). In the present investigation, the concentration of Cl^- ranges between 28.95–33.09 mg/L with an average value to the lake 30.84 mg/L which is in far below the prescribed limits of WHO (1984), 250 mg/L for drinking water. Its concentration above to that imparts water taste and may harm metallic pipes.

The most significant source of fluoride in drinking-water is naturally occurring (WHO, 2004). The concentration of F^- registered ranged 2.31 (at the inlet of Tikurwuha River) to 17.29 mg/L in site S4 (Referral Hospital area) with an average value of 12.83 mg/L to the lake, which is far apart from the recommended limit of F^- concentration for the drinking water WHO (1.5 mg/L) and EEPA (3.0 mg/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). It is the main critical water quality issues in rift valley areas of Ethiopia.

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

pH and turbidity

The pH of the lake water ranged from 7.0 to 7.7 with an average value of 7.5. 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 &Yaregi, 2003). The value of pH decreased in the lake in comparing with 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; EEPA, 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 8.44 NTU. The turbidity of the lake water is higher than the permissible limit

<5 NTU WHO (1984), while WHO (2006) stated that drinking water is best consumed with NTU less than 1NTU for health purposes.

Nitrate-nitrogen, Nitrite-Nitrogen and phosphate

The highest mean value of 8.87 (S2) and 8.46 mg/L (S4) nitrate were obtained in the lake with an average value of 5.27 mg/L to the lake system (**Table 5**). In all observed sites the amounts of nitrate concentration at lake were below the permissible limit of WHO (2004) for drinking uses which is 10mg/l. According to Murdoch *et al.* (2001), high nitrate content (>1 mg/L) is not conducive for aquatic life. Nonetheless, in unpolluted waters the level of nitrate-nitrogen is usually less than 0.1 mg/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 mg/L, 0.031 mg/L and 0.029 mg/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 (0.103 mg/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 be greater than 0.001 mg/L (Chapman, 1996), however, in the Lake Hawassa it reaches to 0.103 mg/L.

The highest phosphate concentration observed at recreational area (1.42 mg/L) and inlet of Tikurwuha river (1.36 mg/L) (**Table 5**), these 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 is above the maximum permissible limits according to WHO (1984) and EPA (2003) that may ranges from 0.005-0.02 mg/L in surface water for different purposes and the healthiness of the water ecosystem.

Bacteriological characteristics of Lake Hawassa water

The result of analysis for total coliform (TC) bacteria ranges from 6000 MPN/100 mL (S6) to 20 833 MPN/100 mL (S10) with an average of 11 883 MPN/100 mL which indicates the presence of high contamination. In all areas the value is beyond the recommended maximum permissible limits of

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

Parameters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
NO_3^-	3.02±0.86^{a}	8.87±0.83^{j}	6.29±2.99^{h}	8.46±3.82^{i}	5.26±1.76^{g}	4.47±2.29^{d}	3.84±0.598^{c}	3.30±0.980^{b}	4.64±1.37^{f}	4.54±1.52^{e}
$PO4^{-3}$	1.36±0.15^{g}	1.11±0.23^{d}	0.98±0.18^{b}	1.07±0.12^{c}	1.15±0.17^{e}	0.99±0.16^{b}	0.97±0.12^{b}	0.85±0.15^{a}	1.28±0.20^{f}	1.42±0.28^{h}
NO_2^-	0.103±0.189^{b}	0.033±0.006^{a}	0.054±0.023^{a}	0.025±0.004^{a}	0.032±0.007^{a}	0.027±0.006^{a}	0.028±0.005^{a}	0.021±0.009^{a}	0.024±0.006^{a}	0.026±0.004^{a}
TN	3.08±0.84^{a}	8.91±0.83^{e}	6.35±3.01^{d}	8.49±3.82^{e}	5.29±1.76^{cd}	5.61±4.77^{cd}	3.87±0.59^{ab}	3.32±0.98^{a}	4.67±1.37^{bc}	4.57±1.52^{bc}
TP	0.449±0.046^{i}	0.367±0.076^{f}	0.325±0.060^{c}	0.354±0.040^{e}	0.378±0.054^{g}	0.328±0.053^{d}	0.320±0.038^{b}	0.281±0.049^{a}	0.424±0.064^{h}	0.509±0.093^{j}
TN/TP	6.79±1.70^{a}	24.87±3.56^{j}	19.16±8.39^{h}	23.87±11.08^{i}	13.67±3.28^{f}	14.72±8.49^{g}	12.30±2.58^{d}	12.62±5.15^{e}	10.99±3.05^{c}	10.76±5.72^{b}
Chlla	27.88±6.42^{h}	28.35±2.20^{i}	36.64±11.54^{j}	24.08±4.45^{b}	24.46±3.46^{f}	23.19±4.88^{d}	22.85±2.61^{c}	19.37±4.02^{a}	21.54±4.28^{b}	26.09±14.34^{g}

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 (*chlorophyll-a*) which is in µg/L

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

Parameters	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
TC	12,333^{g}	15,833^{i}	12,167^{f}	9,500^{c}	12,833^{h}	6,000^{a}	8,667^{b}	10,667^{e}	10,000^{d}	20,833^{j}
FC	213^{j}	130^{h}	63^{c}	78^{e}	47^{a}	67^{d}	58^{b}	85^{f}	92^{g}	163^{i}

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).

WHO (2006), and EU (1998), zero/100 mL for the drinking, irrigation and recreational uses. The value of total coliform is beyond the acceptable limits for untreated freshwater used for unrestricted irrigation of row consumed crops as well as fishing (CCEM, 1999) and WHO (1989), 1000 MPN/100 mL in all sampled sites (**Table 6**). Based on this actuality the lake water was highly contaminated by bacteriological aspects and it does not fit for irrigation, drinking, recreation and fishing purposes. The fecal coliform amount of the lake was above the recommended limits of the shellfish harvesting water, i.e., 14 MPN/100 mL as a guideline of USEPA (1976) (**Table 6**).

Irrigation Water Quality Assessment

Total salinity (TDS/EC)

Salts of calcium, magnesium, sodium, and potassium were present in the irrigation water may prove to be injurious to plants. But the values of TDS at the entire sampled site are below 1000 mg/L (**Table 3**) and they are considered to be excellent for irrigation uses according to Robinove *et al.* (1958). The TDS of the Lake Hawassa (455.6 mg/L) were comparable with the Lake Ziway which ranges from 200 to 400 mg/L (Hengsdijk & Jansen, 2006).

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

The SAR value obtained in the present study ranged from 12.20 (S1) to 16.01 meq/L (S7), with an average value of 13.37 meq/L for the lake system (**Table9**). According to the standard presented by Ayers and Westcot (1985) and Richards (1954), the result obtained falls under the category C2S2 (**Tables 7&8**). That means the result indicating medium alkali hazards and good irrigation water (US Salinity Laboratory Staff, 1954).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, 1958) for the irrigation water use. High percentage of sodium on irrigation water may stunt the plant growth, defflocculation and reduces the soil permeability (Joshi *et al.*, 2009; Singh *et al.*, 2008). The analyzed water results of the MAR value ranged between 93.8% (S2) and 95.4% (S10) with an average value of 94.5%, which indicating they are above the acceptable limit of 50% (Ayers & 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.

Table 7. Limits of some parameter indices for rating water quality and its sustainability in irrigation (Ayers and Westcot, 1985; Eaton, 1950; Wilcox, 1958; 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

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

Table 9. Summary of various indices for irrigation water quality statistics of lake water (Mean ± SD, n = 18)

Indices	Sampling sites in Lake									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SAR	12.19± 5.26	14.22± 3.21	12.81± 3.62	13.91± 4.57	13.22± 3.89	12.98± 3.95	16.01± 1.85	12.63± 3.55	13.17± 3.91	12.56± 4.42
SSP	84.04± 7.41	88.34± 1.81	86.46± 4.88	86.08± 5.73	85.93±5 .56	85.47± 5.48	88.29± 2.61	85.47± 5.31	86.26± 5.36	83.78± 7.99
KR	5.74± 2.83	6.89±1 .06	6.31± 2.05	6.42± 2.62	6.25±2. 38	6.06± 2.41	7.18± 1.51	5.82± 1.98	6.34± 2.17	5.71± 2.48
MAR	94.23± 1.52	93.84± 1.07	93.94± 1.31	94.53± 1.40	94.55±1 .83	94.80± 1.29	94.40± 1.37	94.92± 0.97	94.57± 1.26	95.37± 1.51

Note: The analytical results were statistically significant at $P < 0.05$.

Based on this view the investigation of the lake water was in category class II or good for irrigation uses. The value of KR to the lake ranged between 5.71 meq/L at site S10 and 7.18 meq/L at site S7 with an average value of 6.27 meq/L (**Table 9**). 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 and may cause great permeability problem.

Major cations and anions in water

An average sodium content of the lake water value was 14.4 meq/L (**Table 4**). The obtained value is far above the recommended limits for irrigation use (UCCC, 1974), but within the range according to Ayers & Westcot (1985), i.e., 0−40 meq/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 causes 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 0.13meq/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 1.99 meq/L to 2.63 meq/L with an average value of 2.31 meq/l which is within the recommended limits (Ayers &Westcot, 1985).

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

Recreational Water Quality Analysis of the Lake

An average total coliform count of the Lake Hawassa was 11 883 MPN/100 mL which is above the recommended limits of WHO (1989), BSI (2003) and CCEM (1999) for the recreational purposes (<500 MPN/100 mL) and the fecal coliform values also same to TC which is above the limit (**Table6**). The TC count of the lake is also greater than the mean TC count of Lake Babogaya (117.8±24.3M PN/100 mL) and Lake Hora (73.2±7.6 MPN/100 mL) (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 (CCEM, 1999), i.e., Secchi depth value of 1.2 m 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 (CCEM, 1999) (<5 NTU); 8.44 NTU 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.

Trophic State Index (TSI) of the Lake Hawassa

The trophic state indices calculated for the Lake Hawassa water were TSI (Chll-a) 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 10**). 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).

Table 10. Carlson's Trophic State Index for the Lake Hawassa

Site of sampling	Means of components					Tropic 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	27.88	0.50	3.08	6.792	92.21	63.25	70.13	70.68	75.20	74.06
S2	366.8	28.35	0.63	8.91	24.87	89.3	63.41	66.77	86.01	73.16	76.37
S3	324.5	36.64	0.66	6.35	19.16	87.53	65.93	65.87	81.12	73.11	75.11
S4	353.9	24.08	0.68	8.49	23.87	88.78	61.81	65.66	85.31	72.08	75.39
S5	378.4	24.46	0.66	5.29	13.67	89.75	61.91	65.98	78.49	72.56	74.03
S6	327.7	23.19	0.75	5.61	14.72	87.67	61.44	64.14	79.34	71.08	73.15
S7	319.5	22.85	0.68	3.87	12.30	87.31	61.29	65.66	73.98	71.42	72.06
S8	281.1	19.37	0.68	3.32	12.62	85.46	59.68	65.55	71.76	70.23	70.61
S9	424.1	21.55	0.66	4.67	10.99	91.39	60.72	65.98	76.69	72.70	73.70
S10	509.6	26.11	0.64	4.57	10.76	94.04	62.60	66.54	76.38	74.39	74.89
Overall total tropic 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.

Typically, phosphorus is the single best chemical indicator of the condition of a nutrient-rich lake. Algae need as little as 0.02 mg/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 0.28 mg/L at site S8 to 0.51 mg/L at the site S10 with an average value of 0.37 mg/L to the whole lake system. The overall phosphorus concentration greater than 300 µg/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 (2005) the level of total nitrogen in water above 1.1 mg/L indicates the most-disturbances of the aquatic body by the nutrient through human induced action, but the lake water TN is in average 5.42 mg/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 is closed basin lake (Calgary, 2005).

The nutrient limitation was estimated by using the ratio of TN:TP in the lake water and it is 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 was ranged from 6.79(S1) to 24.87(S2) with an average value of 14.98 (**Table 10**). The ideal ratio of nitrogen to phosphorus ratio for aquatic plant growth is 10:1(EPA, 1990), but the ratio increases to 16:1 according to Redfield (1958). Ratios higher than 10 indicates a phosphorus-limited system (EPA, 1990). 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.

The concentration of chlorophyll-a was ranged between 19.37 µg/L and 36.64 µg/L with an average value of 25.45 µg/L. The increase in the mean chlorophyll-a concentration from 18.4 µg/L (Girma & Ahlgren, 2009) to 36.64 µg/L (in the present study) which shows an increase in the productivity of the lake that can be attributed to human activities in the watershed.

The Lake Hawassa had low transparency throughout the whole sampling site ranged from 0.50 to 0.75m and, therefore, is generally regarded as a productive lake. As Thornton (1986), 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 26years for the Lake Hawassa.

Heavy Metals Analysis for the intended uses

Tiny amount or trace levels of dissolved metals in surface water are essential for proper biological functioning (CCEM, 2009). Many are important in basic physiological functions in both plants and animals, as blood components or cofactors in enzyme reactions (CCME, 1999). The maximum average concentration values were registered in the Inlet of Tikurwuha River for Zn (0.317 mg/L), Fe (0.18 mg/L), Cu (0.046 mg/L) and Mn (0.489 mg/L) (**Table 4**). 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 and Pb were non-detectable; these make the lake water suitable for aquatic life like fish. The study value of heavy metals results were agrees with the former investigation of Lake Hawassa done by Zinabu & Pearce (2003). Based on the result obtained (heavy metals found) in the lake water was suitable for drinking, irrigation and aquatic uses (USEPA, 1998; WHO, 1984; 1998).

CONCLUSIONS

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^- (12.8 mg/L), Na (331.14 mg/L), BOD (117 mg/L), COD (48.73 mg/l), K (70 mg/l) and bacteriological parameters like TC (11 883 MPN/100 mL) and FC (99.69 MPN/100 mL) which were above the recommended standard values of WHO, USEPA and 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 condition. The water quality parameters evaluated to observe the ability of the lake to sustain the aquatic life revealed that it is 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. Since the current research is only limited to one season (dry season).

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