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Full Length Research Paper

Water quality index of fresh water streams feeding Wular Lake, in Kashmir Himalaya, India

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The quality of drinking water is of vital concern for human health and life. The present investigation was aimed at assessing the water quality index (WQI) of five fresh water streams feeding Wular lake. Analysis of the data revealed that the WQI values ranged from a minimum of 45.4 to a maximum of 48.9. Among the study sites, Makdhoomyari stream showed higher values of WQI while as lowest was shown by Madhumati. Pearson matrix revealed that conductivity showed significant positive correlation with total dissolved solids ($P < 0.01$, $r = 0.807$) and total alkalinity ($P < 0.01$, $r = 0.635$). Total hardness was found to bear strong positive correlation with calcium ($P < 0.01$, $r = 0.819$), while temperature maintained inverse relationship with dissolved oxygen ($P < 0.01$, $r = 0.78$). The results support that the water parameters are desirable and the water quality of these streams falls under Category I based on water quality index values. Bray Curtis similarity dendrogram depicted that Erin and Gurura streams had maximum (99%) similarity; while as lowest similarity was observed between Makdhoomyari and Ashtungu streams (85.98%). The present finding revealed that these streams need immediate attention to prevent them from further deterioration.

Key words: Water quality index, Wular lake, Pearson correlation, Kashmir, Himalaya.

INTRODUCTION

The fresh water streams in Kashmir Himalaya are the potable sources of water for the region but unfortunately due to their exploitation for various purposes like drinking, domestic, agriculture, hydropower, etc. These vital resources are getting not only degraded but also polluted as the human population grows. Comparatively, little work has been done on the stream ecosystems of the Kashmir valley and it is only very recently some work have been conducted on the physicochemical and biological aspects of streams (Rashid et al., 2006; Bhat et al., 2011; Hussain and Pandit, 2011). Further, very recently, WQI was applied to evaluate the water quality of Vishav stream in Kashmir (Hamid et al., 2013). However, no substantial work on WQI has been carried out on the incoming streams of Wular lake, the largest fresh water lake in Indian subcontinent.

MATERIALS AND METHODS

Description of the study area and sites

Wular Lake is the largest fresh water body in the Indian Sub-continent is located 34 km northwest of Srinagar city. Geographically, the lake is situated at an altitude of 1,580 m (a.m.s.l), between 34°16´-34°20´N latitudes and 74°33´-74°44´E longitudes and covers an area of 189 km^2 (Shah et al., 2014). For

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Table 1. Location of five sampling sites around Wular lake.

Site	Sampling sites	Latitude E	Longitude N	Elevation
I	Makhdoomyari	34°17´39.8´´	74°37´-29.6´´	1586
II	Gurura	34°22´37.6´´	74°40´-21.7´´	1598
III	Erin	34°24´26.5´´	74°39´10.2 ´´	1599
IV	Madhumati	34°25´30.7´´	74°37´45.1´´	1594
V	Ashtang	34°24´30.3´´	74°32´23.6´´	1585

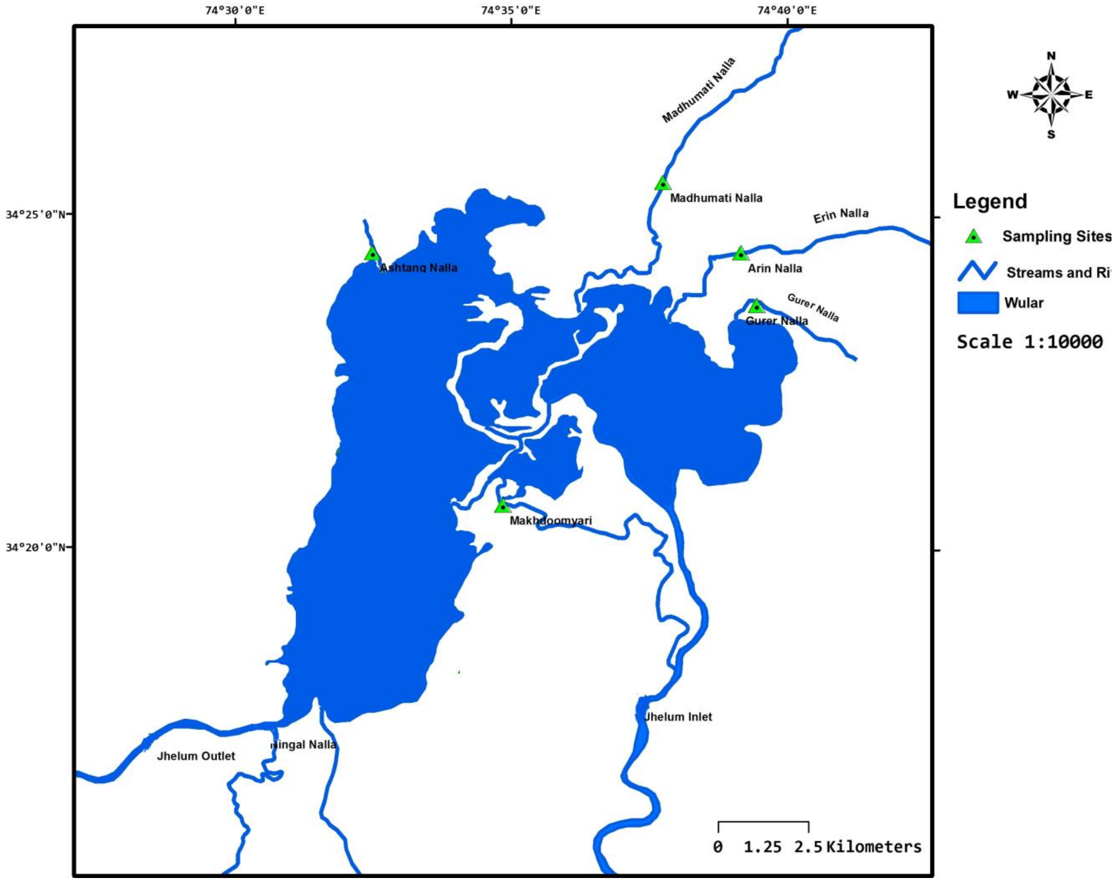

Figure 1. Location map of the study area with sampling stations.

the present investigation, five streams namely Makhdoomyari, Gurura, Erin, Madhumati and Ashtungu were selected which directly drain into the Wular lake for the assessment of water quality and calculation of Water Quality Index (Table 1 and Figure 1).

Sample collection and analysis

Surface water samples were collected in clean polyethylene bottles for the analysis of various physico-chemical parameters on monthly basis from December, 2011 to November, 2012. Parameters like water temperature and pH were measured on spot by means of a mercury thermometer and digital pH meter. The remaining parameters were analysed in the laboratory as per the standard methods of APHA (2005).

Statistical analysis

Statistical analysis were performed using SPSS (statistical version 16 for windows 7, SPSS and Chicago, IL,USA). The relation between various study sites were calculated by another software programme PAST (statistical version 1.93 for windows 7).

Calculation of Water Quality Index (WQI)

Eight water parameters were considered for calculation of water quality index (Tiwari and Manzor, 1988; Mohanta and Patra, 2000; Kesharwani et al., 2004; Padmanabha and Belagalli., 2005):

Water Quality I index (WQI) = $\Sigma qiwi$

Table 2. Physico chemical characteristics and water quality index at Site I.

Parameter	WHO Standard	Wi (unit weight)	Mean (±) S.D	WIQI
Temperature (ºC)	……		14.1±8.2	-
pH	8.5	0.319	7.8±0.3	17.01227
EC (µS/cm)	750	0.0036	232.3±80.8	0.111979
TDS (mg/l)	500	0.0054	155.6±54.1	0.112509
DO (mg/l)	5	0.5423	9.1±1.6	31.06837
Total alkalinity (mg/l)	200	0.0136	91±18.3	0.164498
Total hardness (mg/l)	300	0.009	133±41.3	0.16028
Calcium (mg/l)	75	0.0362	53.3±17.6	0.25693
Chloride (mg/l)	250	0.0108	10.4±4.2	0.01504
Nitrate (mg/l)	45	0.0603	0.76±0.33	0.00612
Water Quality Index ∑WiQi = 48.91				

Table 3. Physico chemical characteristics and water quality index at Site II.

Parameter	WHO Standard	Wi (unit weight)	Mean (±) S.D	WiQi
Temperature (ºC)	……		13.4±7.9	-------
Ph	8.5	0.319	7.8±0.3	17.01227
EC (µS/cm)	750	0.0036	214.3±64.8	0.103302
TDS (mg/l)	500	0.0054	143.5±43.4	0.10376
DO (mg/l)	5	0.5423	9.3±1.6	29.94038
Total alkalinity (mg/l)	200	0.0136	91.6±21.1	0.165582
Total hardness (mg/l)	300	0.009	124.2±37.3	0.149675
Calcium (mg/l)	75	0.0362	45.2±12.8	0.217884
Chloride (mg/l)	250	0.0108	10.1±3.6	0.014606
Nitrate (mg/l)	45	0.0603	0.80±0.4	0.006427
Water Quality Index ∑WiQi = 47.7				

Where qi (water quality rating) = 100 x (Va- Vi) / (Vs-Vi), when Va = actual value present in the water sample, Vi = ideal value (0 for all parameters except pH and dissolved oxygen which are 7.0 and 14.6 mg/L respectively). Vs = standard value. If quality rating qi = 0 means complete absence of pollutants, While 0< qi < 100 implies that, the pollutants are within the prescribed standard; When qi > 100 implies that, the pollutants are above the standards:

Wi (unit weight) = K / Sn

$$\mathrm{K(constant)} = 1 + \frac{1}{\frac{1}{Vs1} + \frac{1}{Vs2} + \frac{1}{Vs3} + \frac{1}{Vs4} + \cdots \frac{1}{Vsn}}$$

Where , Sn = ‘n’ number of standard values.

RESULTS AND DISCUSSION

The annual average values of various physico-chemical properties and water quality index of five streams are presented in Tables 2 to 6 and in Figure 2. During the present study, the annual mean water temperature ranged from 12.8 to 14.8°C, with highest temperature being recorded at Site I and lowest at Site III. The higher temperature during the summer season can be attributed probably to high atmospheric temperature, low relative humidity (Sinha et al., 2004; Ayoade et al., 2006; Atobatele and Ugwumba, 2008). pH is an important parameter in water quality assessment as it influences many biological and chemical processes within a water body (Gray, 1999; Shah and Pandit, 2013). In this present study, pH value ranged between 7.7 at Site V to 7.9 at Site III. In the majority of studies conducted on freshwater ecosystems, the pH values are generally reported between 6 and 9 (Kamran et al., 2003).

Specific conductivity in aquatic ecosystems depends on ionic concentration or dissolved in organic substances. It can also be used to give a rough estimate of the total amount of dissolved solids in water. In the present study, the highest conductivity of 232 µScm^{-1} was registered at Site I as against the lowest of 123.7 µScm^{-1} being recorded at Site V. The high conductivity values recorded at Site I can be due to excessive use of agricultural fertilizers (Clenaghan et al., 1998).

A total dissolved solid is very useful parameter

Table 4. Physico chemical characteristics and water quality index at Site III.

Parameter	WHO Standard	Wi (unit weight)	Mean (±) S.D	WiQi
Temperature (ºC)	……		12.8±7.2	
pH	8.5	0.319	7.9±0.3	19.14
EC (µs/cm)	750	0.003615	215.6±70.2	0.103929
TDS (mg/l)	500	0.005423	144.4±47.0	0.104411
DO (mg/l)	5	0.5423	9.8±1.3	27.115
Total alkalinity (mg/l)	200	0.013558	90.4±22.6	0.163413
Total hardness (mg/l)	300	0.009038	118.2±35.5	0.142444
Calcium (mg/l)	75	0.036153	44.1±15.9	0.212582
Chloride (mg/l)	250	0.010846	9.1±2.9	0.01316
Nitrate (mg/l)	45	0.060256	0.80±0.4	0.006427
Water Quality Index ∑Wi Qi = 47.00				

Table 5. Physico chemical characteristics and water quality index at Site IV.

Parameter	WHO Standard	Wi (unit weight)	Mean (±) S.D	WiQi
Temperature (ºC)	……		13.6±7.7	-------
pH	8.5	0.319	7.7±0.2	14.88773
EC (µs /cm)	750	0.003615	123.7±39.6	0.059629
TDS (mg/l)	500	0.005423	142.1±56.4	0.102748
DO (mg/l)	5	0.5423	9.1±1	31.06837
Total alkalinity (mg/l)	200	0.013558	94.3±18.8	0.170463
Total hardness (mg/l)	300	0.009038	123.7±39.6	0.149072
Calcium (mg/l)	75	0.036153	47.7±13.1	0.229935
Chloride (mg/l)	250	0.010846	11.7± 5	0.01692
Nitrate (mg/l)	45	0.060256	0.6±0.2	0.00482
Water Quality Index ∑WiQi = 46.68				

Table 6. Physico chemical characteristics and water quality index at Site V.

Parameter	WHO Standard	Wi (unit weight)	Mean (±) S.D	WiQi
Temperature (ºC)	-	-	13.2 ±7.7	-
pH	8.5	0.319	7.9±0.4	19.14
EC (µs /cm)	750	0.003615	211.3 ± 68.5	0.101856
TDS (mg/l)	500	0.005423	141.6 ± 45.9	0.102386
DO (mg/l)	5	0.5423	10 ± 1.6	25.54233
Total alkalinity (mg/l)	200	0.013558	95.5 ± 22.4	0.172632
Total hardness (mg/l)	300	0.009038	117.3 ± 22.3	0.14136
Calcium (mg/l)	75	0.036153	42.9 ± 13.6	0.206797
Chloride (mg/l)	250	0.010846	8.9 ± 3.8	0.012871
Nitrate (mg/l)	45	0.060256	0.7 ± 0.3	0.005624
Water Quality Index ∑WiQi = 45.43				

describing chemical constituents of the water and can be in general related to the edaphic factor that contributes to the productivity within the water body (Goher, 2002). In the present study, total dissolved solids fluctuated between a high of 155.6 mg/L at Site I and a low of 82.9 mg/L at Site V. The concentration of total dissolved solids tends to be higher at Site I due to increased siltation caused by surface run-off (Shinde, 2011). Dissolved

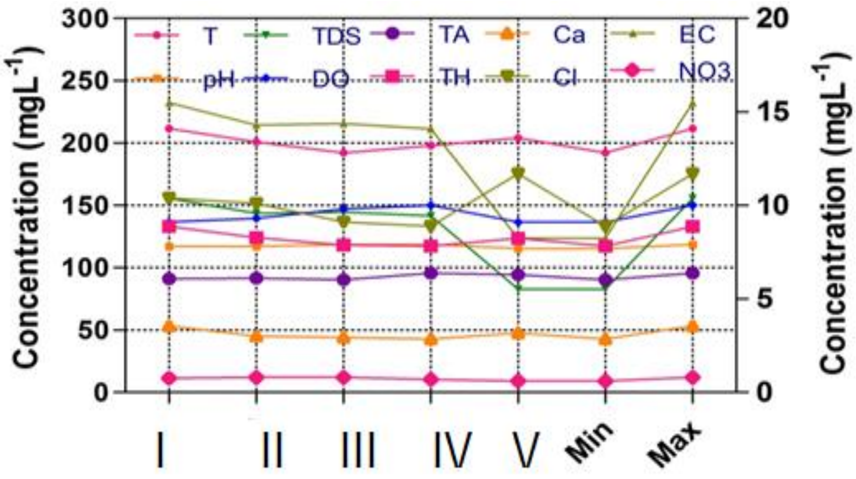

Figure 2. Spatial variation of annual average physico chemical characteristics of water.

oxygen is of paramount importance in all aquatic ecosystems as it regulates most of metabolic processes of organism and also the community architecture as a whole (Hussain and Pandit, 2011). The highest amount of dissolved oxygen (10 mg/L) was noted at Site IV while the lowest dissolved oxygen of 9.1 mg/L was evinced at Site V.

Alkalinity of water is the capacity to neutralize strong acids and is primarily a function of carbonate, bicarbonate and hydroxide content, being formed due to the dissolution of carbondioxide in water (Dallas and Day, 2004). During the present investigation, the maximum alkalinity of 95 mg/L was registered again at Site IV as against the minimum of 90.4 mg/L, being registered at Site III. The lower alkalinity values in the present investigation may be attributed to the high flow discharge (Harlow, 2003).

Hardness usually includes only Ca^{2+} and Mg^{2+} ions expressed in the terms of equivalent $CaCO_3$ (Das and Singh, 1996). During the entire study period, the highest value of total hardness (133 mg/L) were maintained at Site I as against the lowest of 117.3 mg/L at Site IV. The slightly higher hardness values may be attributed to the increased mobilization of elements (calcium and magnesium) from subsurface ground (Badrakh et al., 2008). Calcium is present in all waters as Ca^{2+} and is readily dissolved from rocks rich in calcium minerals, particularly as carbonates and sulphates, especially limestone and calcite (Chapman, 1996). In the present study the values of calcium hardness ranged between a high of 53.3 mg/L at Site I and a low of 42.9 mg/L at Site IV. The higher concentration of Ca^{2+} at Site I is the direct attribute of the lithology of catchment area as suggested by the findings of (Jaiswala et al., 2009). Chloride is chemically and biologically unreactive and it occurs naturally in all types of water. It enters surface waters, with the weathering of some sedimentary rocks (mostly rock salt deposits) and from industrial and sewage effluents, and agricultural and road run-off (Link and Inman, 2003). In the present study, the levels of chloride fluctuated between 11.7 mg/L at Site V and 8.4 mg/L at Site IV. The highest chloride concentrations at Site V may be explained on the account of the increasing anthropogenic activities (Mooers and Alexander, 1994).

Nitrate-nitrogen is known to be a vital nutrient for growth, reproduction, and the survival of organisms. In the present investigation, the concentration of nitrate could not show marked fluctuations and ranged from (0.6 mg/l) to (0.8 mg/l). Higher levels of nitrate were obtained at Sites II and III, while as lower levels were registered at Site V. High nitrate levels (>1 mg L^{-1}) are not good for aquatic life (Kilham, 1990). Further, the fluctuations noticed in the concentration of nitrate may be attributed to increased agricultural runoff and sewage contamination (Ali et al., 1999).

Water quality index (WQI)

The concept of water quality index (WQI) is based on the comparison of water quality parameters with respect to regulatory standard (Khan et al., 2003). WQI is defined as a rating that reflects the composite influence of different water quality parameters. WQI is calculated from the point of the suitability of surface waters for variety of uses including human consumption (Cude, 2001; Atulegwu and Njoku, 2004).

Analysis of the data revealed that the WQI values for the streams fluctuated from a high of 48.9 at Site I and to a low of 45.4 at Site IV with an average value of 47.1 ± 1.3 (Figure 3). Higher values of WQI obtained at Site I may be attributed to the fact that it drains out through the large catchment surrounded by huge tracts of agriculture fields and also has severe anthropogenic stresses as

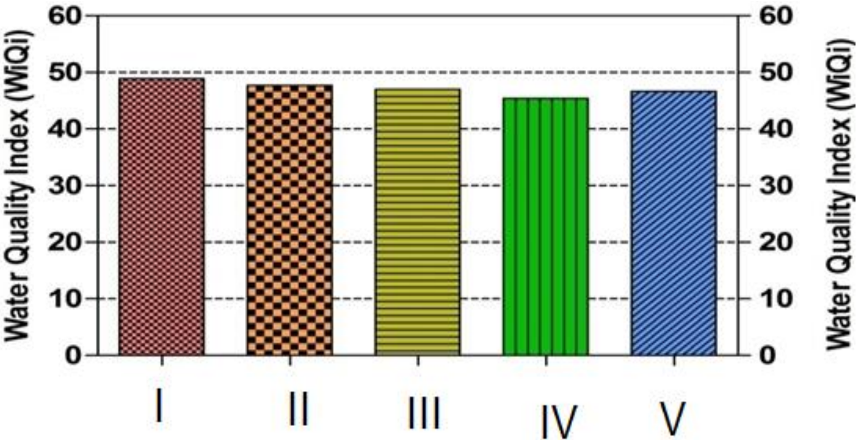

Figure 3. Variation of WQI of five study sites.

compared to other sites. On the other hand, lower WQI values obtained at Site IV may be on the account of its glacier fed nature, being surrounded by catchments of dense forests and meadows (Kanth and Hassan, 2012). The findings of the present study revealed that the water quality parameters are desirable and the water quality of these stream falls under Category I (that is, slightly polluted based on water quality index values) as per (Sinha et al., 2004). Yet, they need immediate attention as they are main sources of water to Wular lake.

Relationship among hydrological parameters

In the present study, water temperature showed negative correlation with almost all the parameters. The parameters depicting highly significant negative correlation with water temperature were dissolved oxygen ($P < 0.01$, $r = -0.784$), (Gurumahum et al., 2002; Idowu et al., 2013), nitrate ($P < 0.01$, $r = -0.820$) (Shah and Pandit, 2012), total dissolved solids ($P < 0.01$, $r = -0648$) and total hardness ($P < 0.01$, $r = -0.676$). Conductivity revealed highly significant positive correlation with total alkalinity ($P < 0.01$, $r = 0.635$). However, the highly significant positive correlation between conductivity and total dissolved solids was evident from the results which was proved statistically ($P < 0.01$, $r = 0.807$) (Heydari and Abbasi, 2013). The most significant positive correlation of total dissolved solids was recorded with total alkalinity ($P < 0.01$, $r = 0.765$) and chloride ($P < 0.01$, $r = 0.655$). Total hardness was found to bear strong positive correlation with calcium ($P < 0.01$, $r = 0.819$) (Kumar and Sinha, 2010) pH was the only exception which could not depict strong positive correlation with any of the parameters. The relationship among hydrological attributes has been also diagrammatically shown in Figure 4.

Bray Curtis similarity analysis shows that Sites II and III have maximum (99%) similarity, while as lowest similarity was observed between Sites I and V (Figure 5). This may be attributed to the fact that the former two sites are very close to each other and both the streams have almost same origin but drain through different watersheds of almost similar catchment, Sites I and V are totally dissimilar due to the fact that Site I is an inlet of river Jhelum, perennial in nature and drains out through large catchment while as site V is a stream having very low flow and thus has large quantity of pollutants due to the absence of strong dilution effect also carries out with itself the whole domestic sewage of villages present in its banks immediately into the Wular lake, hence has great anthropogenic stress.

Conclusions

From the observations, it may be concluded that among five streams, the water quality of all the streams is slightly polluted based on water quality index. The study revealed that these streams are experiencing initial stage of anthropogenic stress pollution and needs immediate attention of aquatic ecologists. Further, the results of the study could be helpful in the management of the lake for its water quality, fisheries and recreation. The data obtained could also form baseline and reference point while assessing further changes that might be caused by nature or man in the lake.

Conflict of Interest

The authors have not declared any conflict of interest.

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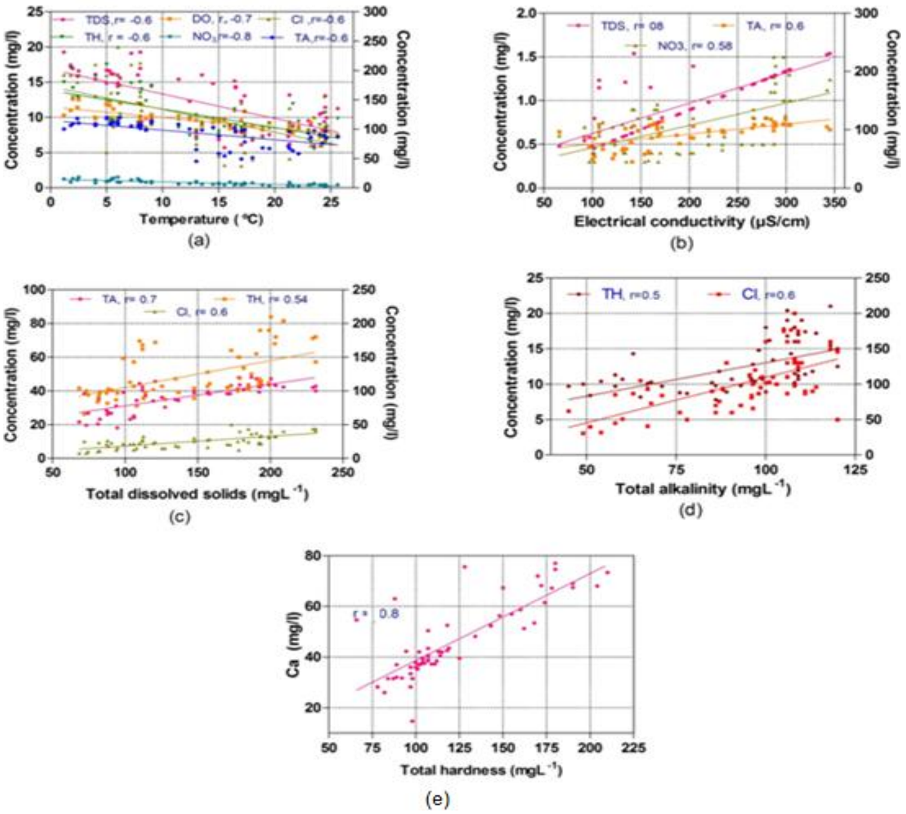

Figure 4. Nature of relationship between physico-chemical parameters of water.

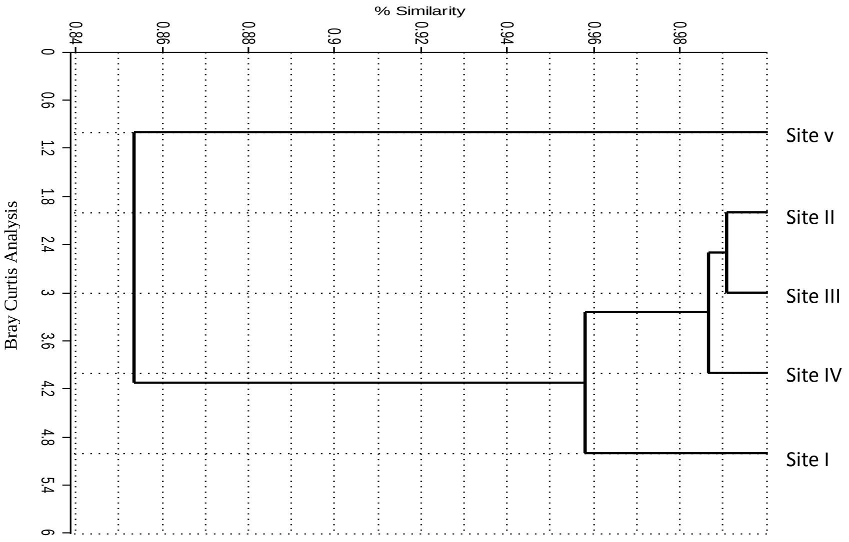

Figure 5. Bray Curtis similarity analysis of study sites.

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Evaluation of the water quality status of Lake Hawassa by using water quality index, Southern Ethiopia

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Lake Hawassa is one of the eight Major Ethiopian Rift Valley Lakes and the smallest among them which is situated in southern regional state; it is a closed basin system and receives water from only perennial Tikurwuha River and runoff from the catchment areas. It is an important source of water for surrounding rural communities for various uses like domestic, irrigation, livestock watering, fishing and recreation. Quality of the lake water is vital for the surrounding rural and urban communities for proper and safe use of the lake. The present study was designed to determine the water quality status of the lake for multiple designated water uses by employing the water quality index. To assess the status water samples were collected in monthly intervals for a period of three months from December to February (dry period), 2011/12. From all water quality parameters analyzed turbidity, Mn, Na^+, K^+, F^-, PO_4^{3-}, total coliform and fecal coliform were higher than the recommended limits of national and international standards for designated water uses. Based on the water quality index calculation the lake water is categorized under marginal category which reveals the water is frequently threatened and impaired and as well departs from natural condition. Accordingly the lake water is under fair category for irrigation and aquatic life; however, it needs great care on selection of crops and soil condition. The lake is under higher risk by deleterious anthropogenic activities on watershed and it needs mitigation measures to prevent it from further deterioration.

Key words: Water quality index, Lake Hawassa, water quality status, designated water use.

INTRODUCTION

Water is an indispensible and basic element which supports life and the natural environment, a prime component for industry, a consumer item for human beings and animals and a vector for domestic and industrial pollution (Colin and Quevauviller, 1998). Access to adequate water for domestic purposes, irrigation, sanitation, and solid waste disposal are the four basic needs which impact significantly on socio-economic development and the standard of life. Status of water quality is highly imperative to the sustainability of natural ecosystems and any development activities and it demands great monitoring and regulation. However, currently the meager freshwater resources are becoming more unconducive for the required uses due to different

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point and non-point sources of pollution from the catchment area.

Water pollution also aggravates the problem of water shortage. Due to this fact the world people living under water-stressed condition ranges from 1.4 to 2.1 billion (Vorosmarty et al., 2000; Oki et al., 2003; Arnell et al., 2004) and peoples affected by unsafe, poor sanitation and hygiene reaches 54.2 million per year with 1.7 millions death (WHO, 2005). So, assessing the status of water quality periodically is quite urgent to save the world from severe water quality initiated functional stress and scarcity.

Ethiopia is a developing country which is endowed with a number of lakes and large rivers which gives immense value to overall economic development. For instance, the country has 12 river basins, 11 fresh lakes, 9 saline lakes, 4 crater lakes and over 12 major swamps/wetlands. However, the water scarcity and inadequacy is the main feature of the country today. In addition to scarcity the quality of water is also threatened as common to all developing countries (Milda, 2009). Among freshwater resources, Lake Hawassa is one of the Major Rift Valley lakes in Ethiopia and used for various purposes by semi-urban and urban dwellers. But the lake has been subjected to many pollutants generated from neighboring industries (like Hawassa Textile factory, floury factory, sisal factory, etc), agriculture activities, service rendering centers (near the lake which release their effluent without any treatment like resorts), hospitals, urban storm water and sewage, and other activities on the catchment (Zinabu and Zerihun, 2002). Specifically, Hawassa textile factory and Hawassa Referal Hospital’s discharge to the lake is seriously degrading its viability since their effluents has become over the set standards to the environment (Yosef et al., 2010; Abayneh et al., 2003; Demeke, 1989).

Research on lakes water quality status on regular basis and its impact on the lake ecosystems and on the potential of the lake water resources for multiple designated uses like drinking, irrigation, recreation and aquatic life are very limited. Therefore, this study was undertaken to avail basic information for the determination of the water quality status of the lake and the main constraining factors that limits its suitability for various designated water uses.

Separate assessment of water quality suitability for the intended uses is time consuming and does not yield appropriate systems to monitor and control the quality of water bodies. Thus, evaluation of the water quality status of the lake by using water quality index is employed. Water quality index (WQI) is one of the most effective tools to aggregate and communicate information on the quality of water to the concerned citizens and policy makers (Puri et al., 2011). It numerically summarizes the information from multiple water quality parameters into a single value that can be used to compare data from several sites and months. The use of WQI simplifies the results of analysis related to a water body as it aggregates in one index of all parameters analyzed (Warhate and Wankar, 2012). There are a number of indices developed in many parts of the world to evaluate water quality status and pollution extents of water bodies like U.S NSFWQI (Sharifi, 1990), BCWQI (CCME, 1995), OWQI (DEQ, 2003), and Smith’s Index (Smith, 1987). For this investigation an indices developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment which is CCME WQI (1.0 model) was used. This index provides a numerical values in between 0 (worst water quality) and 100 (best water quality) with five descriptive categories such as excellent (CCME WQI value = 95-100), good (CCME WQI value = 80-94), fair (CCME WQI value = 65-79), marginal (CCME WQI value = 45-64) and poor (CCME WQI value = 0-44) (CCME, 2001). This study was designed to determine the lake water suitability for drinking, irrigation, recreation and aquatic life by employing the CCMEWQI water quality index calculation method.

METHODOLOGY

Lake Hawassa is one of the eight major Ethiopian Rift Valley lakes which cover an area of about 94km^2 (Yemane, 2004) and the smallest in comparison with other central Rift Valley natural lakes. It is situated 275 km south of the capital city Addis Ababa and west of Hawassa town. The lake is located between 06° 58´to 07° 14´ N latitudes and 38° 22’ to 38° 28’ E longitudes with an elevation of 1685 masl and is bounded by various mountains such as Mt. Tabor (1810 masl) and Mt. Alamura (2019 m.a.s.l) (Yemane, 2004). Hence, the surface and sub-surface drainage is towards the lake and it’s the main destination for any type of contaminants generated from catchment areas. The catchment area of the lake is 1250 km^2 (Girma and Ahlgren, 2009) with closed basin feature and receives only one perennial river from eastern escarpment, Tikur Wuha River. This river is extremely affected by various industries on the basin like Hawassa Textile Factory, Hawassa Sisal factory, Hawassa Flour Factory, Tabor Ceramic Factory, etc (Yosef et al., 2010).

The area receives a mean annual rainfall of 950 mm and has a mean annual air temperature of 19.8°C (Arkady and Brook, 2008). The area is characterized by three main seasons; long rainy season (locally called kiremt) in the summer from June-September (mean annual total rainfall accounts from 50 to 70%), dry period (locally called bega) which extends between October and February and short rain season (locally called belg) during March and May, when about 20 to 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). It has maximum depth of 22 m and a mean depth of 11 m (Elias, 2000). Evaporation from the lake is estimated to be 1710 mm/year, the average annual inflow and outflow(underground flow) is 1440 and 570 mm, respectively as well as the total volume of the lake water is 1.3 km^3(Tenalem, 1998; Gugissa, 2004; Arkady and Brook, 2008).

Grab sampling was done in monthly interval for three months (December 2011 up to February 2012) at ten selected sampling sites from surface 30 cm and 1 m bottom of the lake. The sampling sites are selected based on the relative importance, location and magnitude of human influences. Sample site S1 (Inlet of Tikurwuha River to the lake), S2 (around Haile resort), S3 (around Lewi resort), S4 (Referral Hospital), S5 (at the center of the lake), S6 (direct opposite to Haile resort, rural side), S7 (direct opposite to Lewi

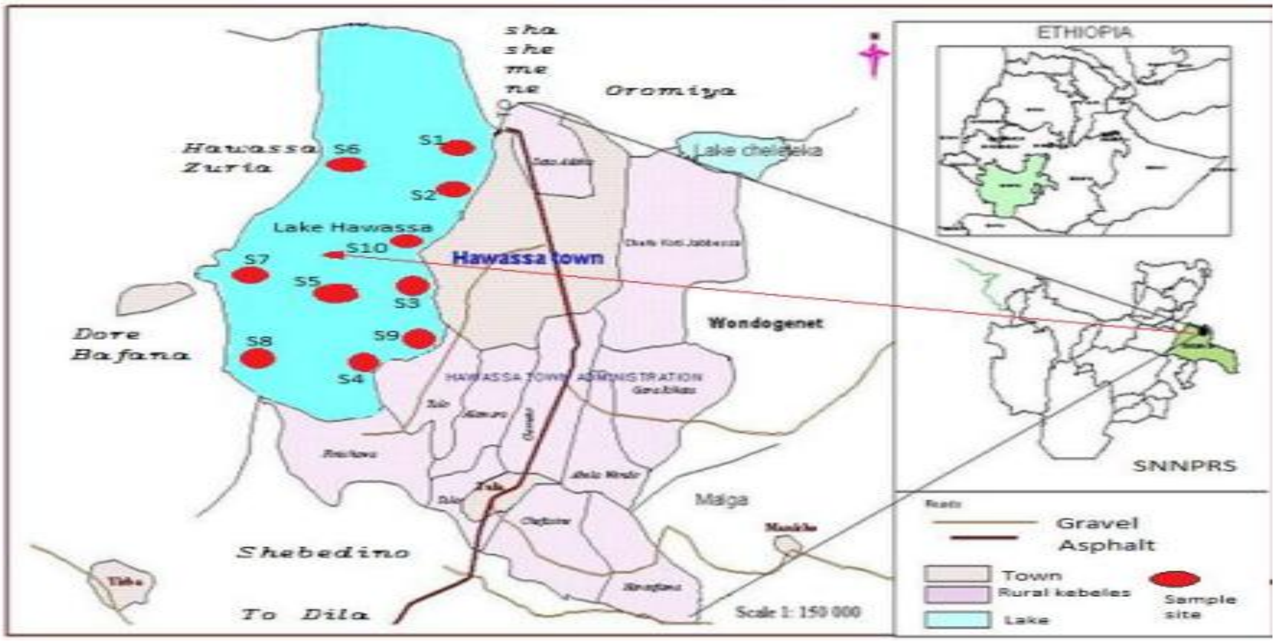

Figure 1. Location map of the study area and sampling sites on the Lake Hawassa.

resort, rural area side, Dore-Bafana), S8 (direct opposite to Referral hospital, rural side), S9 (around Amora-Gedel, town storm water and sewage entrance site) and S10 (around Fikir-Hayike, recreational center) (Figure 1). The water quality parameters analyzed in this study were illustrated on Table 1.

The water quality index was computed following CCME WQI (CCME, 2001) by using the following formula:

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^{\,2} + F_2^{\,2} + F_3^{\,2}}}{1.732} \right)$$

where F_1 (scope)-is the number of variables whose objectives are not met, F_2 (frequency)-is the frequency with which the objectives are not met and F_3 (amplitude)-is the amount by which the objectives are not met. The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

The calculations of these three parameters to determine CCME WQI were described as follows:

1. F_1 (Scope) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration (“failed variables”), relative to the total number of variables measured:

$$F_1 = \left(\frac{Number \cdot of \cdot failed \cdot variables}{Total \cdot number \cdot of \cdot variables} \right) X100$$

2. F_2 (Frequency) represents the percentage of individual tests that do not meet objectives (“failed tests”):

$$F_2 = \left(\frac{Number \cdot of \cdot failed \cdot tests}{Total \cdot number \cdot of \cdot tests} \right) X100$$

3. F_3 (Amplitude) represents the amount by which failed test values do not meet their objectives. F_3 is calculated in three steps:

a. excursion = $\left(\frac{Failed test value}{Objective_j} \right) - 1$

b. nse = $\sum_{i=1}^{n} \frac{excursion}{No.of.total tests}$

c. $F_3 = \left(\frac{nse}{0.01nse + 0.01} \right)$ is an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

The quality criteria of each analyzed parameters were compared to prescribed limits of various international and national standards like WHO (2004), CCME (2009), USEPA (2000), FAO (1985), EEPA(2003) and other guidelines for those designated water uses. After the CCME WQI value was determined with respect to site and month the lake water quality was ranked as per the CCME WQI ranking.

RESULTS AND DISCUSSION

Among analyzed water quality parameters reports which above the recommended limits for drinking water use were turbidity, BOD_5, Mn, fluoride, Na^+, K^+, PO_4^{3-}, total coliform and fecal coliform; for irrigation uses MAR, KR, SPP, and others common to drinking water use; for recreational uses clarity, turbidity, TC and FC as well as

Table 1. Standard water quality parameters determination methods and instruments used.

Parameters	Determination method and instrument
Temp., EC, TDS and salinity	pH and conductivity meter (HANNA pH211)
BOD_5 and DO	Modified winkler-Azide dilution technique
Turbidity	Nephelometeric (HACH, model 2100A)
Secchi depth	20 cm diameter of Secchi disk
NO_3^-, NO_2^-, PO_4^{3-}, NH_3 and 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 and Pb	Determined by atomic absorption spectrometer, AASP (Varian SP-20) using their respective standard hollow cathode lamps (APHA, 1995; APHA, AWWA and WPCF, 1998)
Iron	Determined by using UNICAM UV-300 thermo electrode.
TC and FC	Most probable number method (MPN/100 ml)
Indices (SAR, MAR, SSP, KR and TH)	Richards (1954), Raghunath, (1987), Todd(1980), and Kelly's,(1963) empirical formulas

for aquatic life sustenance Mn, Cu and Zn (Table 2) were the main constraining parameters which were above the recommended limits of WHO, EEPA, CCME,USEPA and FAO guidelines for designated water uses.

pH and turbidity

The determination of pH of the water is very important since it affects the solubility and availability of micronutrients like Zn, Mn, Fe and Cu and how they can be utilized by aquatic organisms and also reduces the performance of water treatment systems and disinfectants in water supply. The pH of the lake water ranged from 6.98 to 7.71 with an average value of 7.54. The value of pH decreased in the lake in comparison to the former research done by Alemayehu (2008), 8.5 and Elizabeth et al. (1994), 8.8. This may reveal the increment of organic matter load to the lake ecosystem as decomposition of organic matter leads to decrease in pH, acidity (WHO, 1984).

Nevertheless, with reference to pH value it is within the permissible limit (6.5-9.0) for drinking, irrigation, recreation and aquatic life (WHO, 2006; CCME, 2001; EEPA, 2003). The consumption of more turbid water may constitute a health risk as excessive turbidity can protect pathogenic microorganisms from the effect of disinfectants, and stimulate the growth of bacteria (Zvikomborero, 2005). The turbidity of the lake water was found to be higher than the prescribed limits (<5NTU) for drinking and recreation purposes (Table 2) (WHO, 1993; CCME, 1999).

BOD_5

BOD is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions (Tenagne, 2009). Unpolluted, natural waters should have a BOD_5 of 5 mg/L or less but on this study the lake water BOD_5 value is on average 117 mg/L. The elevated values of BOD_5 in the lake may show the high level of pollution and it is concentration is beyond the permissible limits of EPA guideline (<5 mg/L) for aquatic, drinking and recreation use (Table 2) (USEPA, 2000).

Na^+ and K^+

The concentration of Na^+ ion ranged from 300.95 to 414.11 mg/L with an average value of 331.14 mg/L which is higher than the permissible limits (200 mg/L) for drinking and irrigation water use (WHO, 1983, 2006). The consumption of eminent Na^+ ion in drinking water leads to hypertension, congenial heart diseases and kidney problems (Singh et al., 2008) where as in irrigation water it may cause crusting, plugging, soil dispersion and sealing of surface pores (FAO, 1985) which leads to infiltration problem and structural instability of the soil. The dominance of Na^+ ion over other major cations could be attributed due to weathering of acidic rocks (Alemayehu, 2008) (Table 2). In all sampled sites the value of K^+ was beyond the permissible limits for drinking and irrigation water use (WHO, 1984). An elevation of potassium in the lake indicates the effect of hospital effluents, septic system effluents, and other anthropogenic activities beside the natural sources.

Fluoride

The most prominent sources of fluoride in water are a natural weathering of mineral bed rocks (WHO, 2004) and it is a common problem mainly in the Rift Valley

Table 2. Mean physicochemical and bacteriological water quality characteristics of the Lake Hawassa in ten sampled sites.

Parameters	Site sample taken										
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**WHO, FAO, CCME**
EC	701	756	752	757	755	755	756	756	756	756	1500
TDS	420.8	454.7	450.7	454	452.2	453.2	453.7	453	455.6	453.5	1000
pH	6.98	7.71	7.58	7.73	7.66	7.54	7.58	7.54	7.53	7.59	6.5-8.5
Temp	21.33	20.98	21.33	21.25	21.17	21.23	21.05	21.25	21.33	21.32	15-30
DO	11.2	17.37	18.35	17.78	18.4	19.17	21.42	20.55	18.85	15.4	>5
Turb.	20.98	7.02	6.98	6.82	6.95	6.98	6.93	6.87	6.92	7.97	<5
Fe	0.180	0.071	0.072	0.078	0.073	0.075	0.074	0.072	0.078	0.080	0.3
BOD$_5$	94.5	56.17	73.33	138.2	92.17	133.5	143	144.8	157.7	136.7	<5
Cu	0.046	0.006	0.005	0.011	0.005	0.005	0.005	0.005	0.005	0.001	2
F$^-$	2.31	14.32	11.83	17.29	14.45	12.36	15.65	13.9	13.27	12.9	1.5
Cl$^-$	31.31	28.95	31.91	33.09	28.95	31.91	28.9	31.91	31.31	30.1	250
TH	124.2	106.1	107.9	126.97	122.6	125.3	130.5	124.7	113.3	137.2	500
Mn	0.489	0.056	0.039	0.043	0.036	0.034	0.056	0.052	0.043	0.040	0.05
Zn	0.32	0.31	0.19	0.16	0.23	0.17	0.12	0.12	0.16	0.16	5
Mg^{2+}	28.54	24.25	24.67	29.24	28.29	28.93	29.96	28.81	26.08	31.92	200
Ca^{2+}	2.72	2.53	2.55	2.68	2.49	2.51	2.92	2.48	2.39	2.34	100
K$^+$	71.82	75.18	70.80	85.04	74.87	70.54	69.46	78.71	71.39	72.76	20
Na$^+$	300.9	341.6	301.3	348.8	325.6	324.1	414.1	317.6	315.6	321.9	200
NO$_3^-$	3.02	8.87	6.29	8.46	5.26	4.47	3.84	3.30	4.64	4.54	45
PO$_4^{3-}$	1.36	1.11	0.98	1.07	1.15	0.99	0.97	0.85	1.28	1.42	0.02
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.003
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02
TC	12333	15,833	12,167	9,500	12,833	6,000	8,667	10,667	10,000	20,833	<50
FC	213	130	63	78	47	67	58	85	92	163	<10
Clari	0.50	0.63	0.66	0.68	0.66	0.75	0.68	0.68	0.66	0.64	1.2*
SAR	12.19	14.22	12.81	13.91	13.22	12.98	16.01	12.63	13.17	12.56	26**
SSP	84.04	88.34	86.46	86.08	85.93	85.47	88.29	85.47	86.26	83.78	60**
KR	5.74	6.89	6.31	6.42	6.25	6.06	7.18	5.82	6.34	5.71	1**
MAR	94.23	93.84	93.94	94.53	94.55	94.80	94.40	94.92	94.57	95.37	50**

All units are in mg L^{-1} saving temperature, turbidity, clarity, EC, and pH which are expressed in °C, NTU, m, µS cm^{-1}, and non-dimensional, respectively. TC and FC units in MPN/100 ml and MAR, SAR, KR and SSP by %. *-indicates only for recreational use and **-express only for irrigation use. The bold ones indicate that analyses result is above the permissible limits except clarity which is below acceptable level.

lakes of eastern African countries (Tamiru, 2006) due to geological factor.

In the present investigation the concentration of fluoride ranged from 2.31 to 17.29 mg/L with an average value of 12.83 mg/L. Drinking water with high fluoride concentration above the permissible limit (1.5 mg/L) may causes dental fluorosis and if continuously consumed for a long period with the concentration 3 to 6 mg/L and above may lead to skeletal fluorosis and skeletal crippling (Kloos and Redda, 1999). The lake water fluoride concentration is twelve times higher than the permissible limits for drinking, irrigation and livestock watering purposes (CCME, 1999; WHO, 1998, 2006) and hence not suitable for these designated purposes.

Nutrients

The most known principal limiting nutrients in freshwater lakes of Rift Valley lakes are nitrogen and phosphorus. Nitrogen can exist in water in four forms like NH$_3$, NO$_3^-$, NO$_2^-$ and NH$_4^+$ which may cause groundwater and surface water pollution in excessive quantity through leaching, stimulate algal growth in surface water that increases maintenance costs in irrigation practices, carcinogenic and blue-baby diseases in infants of human being. But currently the concentration of NO$_3^-$ in Lake Hawassa is within the permissible limit (WHO, 2006; Ayers and Westcot, 1985) for drinking and irrigation. However, the concentration of phosphate is higher than the recommended limits (0.005-0.02 mg/L) to freshwater healthy ecosystem (USEPA, 2000) (Table 2) and hence, the lake is categorized in eutrophic state index as Carlson (1977). However, according to Chapman (1996) the nutrients levels in lake water show great impairment of the lake ecosystem by point and non-point sources of pollution. Nitrite and nitrate should be less than 0.001 and 0.1 mg/l for conducive aquatic life (Murdoch et al., 2001) but lake water has high nutrient contents which depart more from natural desirable levels.

Total coliform and fecal coliform

The concentration of total coliform and fecal coliform in the lake were higher than the recommended limits for drinking water (WHO, 2006) and EU (1998), less than 50 and 10 MPN/100 ml, respectively. Irrigation water requires safe water for production of horticultural crops like vegetables and fruits to prevent transmission of diseases causing pathogens (bacteria, viruses and protozoa). Bacterial diseases such as cholera, typhoid fever, gastroenteritis and salmonellolis may happen when the concentration of total coliform in irrigation water becomes above 1000 MPN/100 ml (WHO, 1983; CCME, 1999). Recreational water quality is highly dependent on bacteriological quantities for direct or indirect recreation. However, the lake has high total and fecal coliform which is above the permissible limits of WHO (1989) and CCME (1999), <500 MPN/100 ml and it impedes the suitability for the required intention (Table 2). In general, the lake water is not suitable for drinking, irrigation, and recreation as well as fin fishes harvesting purposes basically based on bacteriological (TC and FC) concentrations.

Heavy metals

Trace levels of dissolved metals in surface water are essential for proper biological functioning in both plants and animals (CCME, 2009). Generally, the concentration of heavy metals in the lake was relatively high at the Inlet of Tikurwuha River due to point sources of pollution from Hawassa textile factory and other factories which discharge their waste directly into this river. However, except Mn, Cu and Zn other metals such as Cd, Cr, Pb and Ni (Table 2) are within the permissible limits to all designated water uses (CCME, 2009; EU, 1998; WHO, 1998). The level of Mn concentration is higher for drinking uses in three sites and for irrigation and aquatic life in one site (S1) while Cu and Zn content were above the recommended limits to only aquatic life (CCME, 1999; WHO, 1983; USEPA, 2000).

Water quality index (WQI) calculation

The WQI was computed based on the three parameters F_1, F_2 and F_3 for drinking water uses. The values obtained were:

$$F_1 = \left(\frac{Number \cdot of \cdot failed \cdot \text{variables}}{Total \cdot number \cdot of \cdot \text{variables}}\right) X100 = \left(\frac{9}{26}\right) * 100 = 34.62$$

$$F_2 = \left(\frac{Number \cdot of \cdot failed \cdot tests}{Total \cdot number \cdot of \cdot tests}\right) X100 = \left(\frac{87}{2600}\right) * 100 = 3.3$$

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) = \left(\frac{4.562}{0.01 * 4.562 + 0.01}\right) = 81.46$$

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^{\ 2} + F_2^{\ 2} + F_3^{\ 2}}}{1.732}\right) = 100 - \left(\frac{\sqrt{34.62^2 + 3.35^2 + 81.46^2}}{1.732}\right) = 48.86 \cong 49$$

The WQI value computed for irrigation water use was:

$$F_1 = \left(\frac{Number \cdot of \cdot failed \cdot \text{var}iables}{Total \cdot number \cdot of \cdot \text{var}iables}\right) X100 = \left(\frac{9}{20}\right) * 100 = 45$$

$$F_2 = \left(\frac{Number \cdot of \cdot failed \cdot tests}{Total \cdot number \cdot of \cdot tests}\right) X100 = \left(\frac{74}{2000}\right) * 100 = 3.7$$

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) = \left(\frac{0.332}{0.01 * 0.332 + 0.01}\right) = 24.96$$

$$CCMEWQI = 100 - \left(\frac{\sqrt{F_1^{\ 2} + F_2^{\ 2} + F_3^{\ 2}}}{1.732}\right) = 100 - \left(\frac{\sqrt{45^2 + 3.7^2 + 24.96^2}}{1.732}\right) = 70.21 \approx 70$$

The WQI value computed for recreation water use was:

$$F_1 = \left(\frac{4}{6}\right) * 100 = 66.67 \ ; \quad F_2 = \left(\frac{33}{600}\right) * 100 = 5.5 \ ; \quad F_3 = \left(\frac{0.409}{0.01 * 0.409 + 0.01}\right) = 29.01$$

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{66.67^2 + 5.5^2 + 29.01^2}}{1.732}\right) = 58$$

The WQI value computed for aquatic life was:

$$F_1 = \left(\frac{3}{8}\right) * 100 = 37.5 \ ; \quad F_2 = \left(\frac{20}{800}\right) * 100 = 2.5 \ ; \quad F_3 = \left(\frac{0.088}{0.01 * 0.088 + 0.01}\right) = 8.1$$

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{37.5^2 + 2.5^2 + 8.1^2}}{1.732}\right) = 77.8 \approx 78$$

Based on the above separate water quality index computation for the designated water uses, the index for drinking (CCME WQI = 49) and recreational (CCME WQI = 58) purposes falls in marginal category, whereas the index for irrigation (CCME WQI = 70) and aquatic life

(CCME WQI = 78) uses falls within fair category. The overall or cumulative CCME WQI of the Lake Hawassa is 49 and hence it is under marginal category. According to the CCME ranking this water quality is frequently threatened or impaired and its condition often exceeds natural or desirable levels (CCME, 2001). So, mitigation measures should be developed in watershed overall activities, that is, for point and non-point sources of pollutions.

CONCLUSIONS AND RECOMMENDATION

The current study evaluated the physicochemical and bacteriological water quality characteristics of Lake Hawassa for multiple designated water uses like drinking, irrigation, recreation and aquatic life. The parameters of water quality analyzed and examined from various sampling sites in the lake show unsuitability of the water for drinking and recreational uses; but with some great care it is fair for irrigation and aquatic life. Based on the calculated cumulative water quality index it is ranked under marginal category of CCME WQI 49 which indicates the lake water is frequently threatened and impaired for those designated water uses.

Water quality of the lake was highly impaired on the town side of Hawassa that's due to inlets of various factories effluents like Hawassa textile factory, sisal factory, soft drink factory, ceramic factory and sewage as well as regional Hawassa referral hospital effluents. The lake is affected by both point and non-point sources of pollution beside the natural factors. Hence checking the effluent standards of the surrounding factories, controlling the service rendering center waste disposal system and constructing the municipal wastewater and storm water treatment plant are extremely essential to protect the lake water quality from further deterioration.

Conflict of Interest

The authors have not declared any conflict of interest.

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