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ORIGINAL ARTICLE

Evaluation of water quality and eutrophication status of Hawassa Lake based on different water quality indices

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Abstract

Lake Hawassa is one of the major Ethiopian Rift Valley Lakes having an endorheic basin system. The surrounding community makes use of the lake water for the multiple purposes of irrigation, domestic water supply, recreation and fish harvesting. The aim of the present study was to ascertain the water quality of the lake in terms of water quality indices (WQI) and its health over a period of three months covering both dry and wet seasons. Overall, the water quality of Lake was unfit and bad as per the weighted arithmetic method (120.06–228.29) and modified Bascarón water quality index (MBWQI) methods (26.81–33.89), respectively. However, the quality was indicated as marginal, as per the Canadian Council of Ministers of the Environment (CCME) water quality index method (44.2–51.1). On average, the lake was under the hypertrophic stage as per the standard based on the results of Secchi depth and nutrient concentration. The current study showed the lake being unfit for all-purposes as per WAWQI range (> 100). According to the physicochemical and biological parameters, of the lake, it requires mitigation measures to control Eutrophication and pollutants inflow.

Keywords Bascarón · CCME · Eutrophication · Hawassa Lake health · Secchi depth · Weighted Arithmetic

Introduction

Surface water sources have a high vulnerability to pollution than groundwater resources. The lakes are exceptionally easily exposed to pollution due to their size and proximity to the community compared to the ocean or sea and rivers. The plodding accumulation of sediment and organic matter modify the features of the lake such as depth, biological productivity, oxygen levels, and water clarity over a period of time (Steinberger et al. 2019). Furthermore, anthropogenic actions and natural phenomena trigger rapid environmental changes in the lakes which are the most fragile in nature (Abebe Yonas et al., 2018). Human intervention has significant effects on lake water quality due to discharge of domestic, industrial, urban and agricultural wastewaters into the water courses (whether intentional or accidental). The natural influences of geological, hydrological and climatic conditions will impact immeasurably the quality and sustainability of surface water resources. Any significant changes in water quality will usually be disruptive to the ecosystem (WHO, 1996).

Lake Hawassa is the source for commercial fishing in the town of Hawassa. It is also a recreational site and a tourist destination. Moreover, it is the main source of domestic, livestock and irrigation water supplies for the community (Abate et al., 2015). However, the lake Hawassa is one of the most polluted due to discharge of untreated wastewater from domestic and industrial sources, run-off of agricultural wastewater and sediment inflow by rainwater. The commercial establishments like hotels and industries release wastewater into the lake. The fishermen harvest fish and dispose of the internal parts of the fish into the lake. The rapid growth of aquatic plants covered the large surface of the lake. Nevertheless, the lake encounters the high risk of pollution from anthropogenic activities, such as urbanization, intensive agriculture, rapid industrialization and urban runoff and from natural activities such as erosion and heavy rainfall (Price, 2011; Bojarczuk et al., 2018).

The quality of the water body can be determined by using various water quality indices. A water quality index is a tool

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expressed as a single number, developed to describe overall water quality conditions, using multiple water quality variables. The surface water quality assessment can be a complex process that involves multiple parameters capable of causing various stresses on overall water quality (Katyal 2011).

The aim of this research was to identify the current quality and health of Hawassa Lake by using three water quality indices as well as its eutrophic status employing Secchi depth measurements.

Methodology

Study area

The study area, Lake Hawassa, an endorheic freshwater lake, is located between 6°49′ N–7°15′ N latitude and 38°17′ E–38°44′ E longitude with an escarpment of flat to faintly sloping lands and hills at the Southern Nations, Nationality and Peoples Regional State (SNNPRS) and Oromia Regional State, within the Central Ethiopian Rift Valley Basin (Fig. 1). Even though, Lake Hawassa rests at 1680 m above sea level (m.a.s.l), the edges of the caldera's peaks to 2995 m.a.s.l towards the southeast. The streams in the eastern caldera drain to Lake Cheleleka and the associated swamp, which in turn replenishes Lake Hawassa through the perennial river, Tikur Wuha. Although the lake watershed is a closed basin, previous studies have shown that there is groundwater inflow to the lake from the surrounding watersheds and outflow from it to them (Ayenew, 2009; Gebreegziabher, 2005; Tilahun, 2006). The different parts of the catchment could be accessed through the Addis Ababa-Moyale main road and through the network of dry weathered roads.

Sampling

Samples were collected from eleven sampling points following a composite sampling method, using clean, labelled sampling bottles and stored in an icebox. All sample containers were pretreated with dilute hydrochloric acid and distilled water. pH, temperature, dissolved oxygen (DO), total

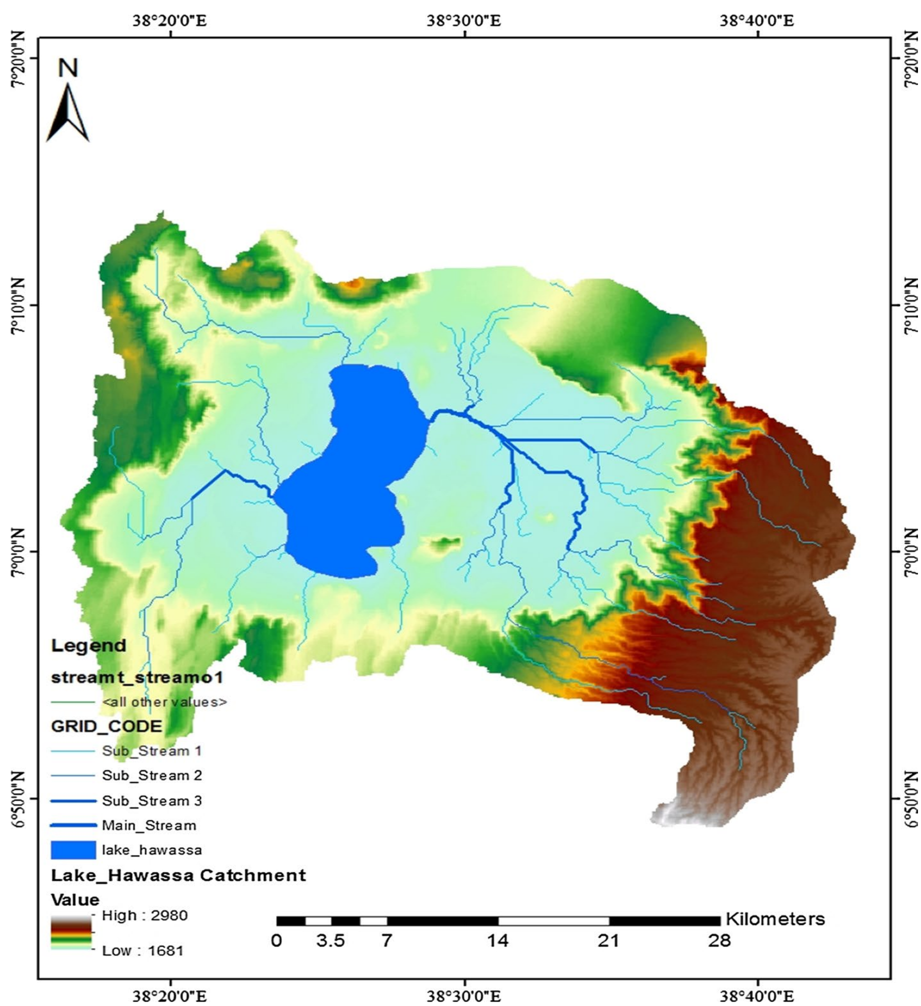

Fig. 1 Study area location map

dissolved solids (TDS), turbidity and electrical conductivity were measured in the field by using digital instruments after their calibration. In the laboratory, samples were analysed for BOD (biochemical oxygen demand), COD (chemical oxygen demand), SS (Suspended solids), nitrate (NO_3^-), and total phosphorus (TP). TSS was determined using the mass loss technique, BOD was determined using the iodometric method, ammoniacal nitrogen was determined using Brucine colorimeteric method, and total phosphate (TP) was determined by using the spectrophotometric method.

Water quality index

Three water quality index methods, viz., weighted Arithmetic index (WAWQI), Canadian Council of Ministers of the Environment water quality index (CCME WQI) and Bascarón water quality index, were used to compare the water quality of the Lake Hawassa.

Weighed arithmetic water quality index (WAWQI) method

The calculation of WQI was made using weighted arithmetic index method in the following steps. Water quality parameters (*n*) and quality rating (qn) corresponding to the *n*th parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. qn values are given by the relationship.

$$q_n = 100*\left(\frac{V_n - V_i}{V_s - V_i}\right) \tag{1}$$

v_s is standard value, v_n observed value, v_i ideal value in most cases v_i 0 except in certain parameters like pH, dissolved oxygen. Ideal value is 7 and 14.6, respectively. Quality rating calculation for pH and DO was mentioned below.

$$q\text{pH} = 100(V\text{pH}-7.0)/\left(V_s-7.0\right) \tag{2}$$

$$q\text{DO} = 100(V\text{DO}-14.6)/\left(V_s - 14.6\right) \tag{3}$$

Calculation of unit weight: The unit weight (Wn) to various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$$Wn = \frac{K}{Sn} \tag{4}$$

where *Wn* unit weight for *n*th parameter, *Sn* standard permissible value for nth parameter, k = proportionality constant. WQI was calculated by the following equation.

$$\text{WQI} = \frac{\sum_{i=1}^{n} qn * Wn}{\sum_{i=1}^{n} Wn} \tag{5}$$

Canadian Council of Ministers of the Environment water quality index (CCME WQI)

CCME WQI provides a consistent method, which was formulated by Canadian jurisdictions to convey the water quality information for both management and the public. Moreover, a committee established under the Canadian Council of Ministers of the Environment (CCME) has developed WQI, which can be applied by many water agencies in various countries with slight modifications. This method has been developed to evaluate surface water for the protection of aquatic life in accordance with specific guidelines. The parameters related to various measurements may vary from one station to the other and sampling protocol requires at least four parameters, sampled at least four times. The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$\text{CCME WQI} = 100-\left(\frac{\sqrt{\text{F1}^2 - \text{F2}^2 - \text{F3}^2}}{1.732}\right) \tag{6}$$

where Scope (F1) = Number of variables, whose objectives are not met.

$$\text{F1} = \left[\text{No. of failed variables /Total no. of variables}\right] * 100 \tag{7}$$

Frequency (F2) = Number of times by which the objectives are not met.

$$\text{F2} = \left[\text{No. of failed tests/Total no. of tests}\right] * 100 \tag{8}$$

Amplitude (F3) = Amount by which the objectives are not met.

excursioni = [Failed test valuei /Objectivej]-1
normalized sum of excursions (nse) = $\sum_{i=1}^{n} excursion_i$ / No of tests
F3 = [nse/0.01nse + 0.01]

Bascarón water quality index

The Bascarón WQI (BWQI) developed by Bascarón from Spain (Bascarón, 1979) has been widely used throughout the world (Kannel et al., 2007; Massoud, 2012; Ismail and Robescu et al., 2019). The overall index is being estimated as subjective water quality index. The equation is given below

$$\text{BWQI} = (\sum_{\text{i=1}}^{\text{i=n}} (\text{Cipi})^2/100 \tag{7}$$

where n = the total number of variables, Ci = value assigned to the variable i after normalization, Pi = relative weight assigned to each variable which ranged from 1 to 4 according to its influence on the water quality (4 for highest impact and 1 for less impact).

The major advantage of BWQI is that numerous water quality variables can be included in calculating the final index after assigning the normalization factors as well as their weights. However, only 22 water quality parameters were found that already have been normalized and weighted in previously reported studies (Kannel et al., 2007; Massoud, 2012). In the present paper, fourteen water quality parameters were included in the evaluation process, namely temperature, pH, EC, turbidity, TDS, total suspended solids, total alkalinity, ammonia, nitrates, total phosphates, dissolved oxygen, COD and BOD. The normalization factors along with their weights given in Table 4 were used for the selected parameters to produce the final BWQI. The classification scheme was adopted to classify water quality (Dojlido et al., 1994).

Water quality rating for Weighed Arithmetic Index (WAWQI), Canadian Council of Ministers of the Environment water quality index (CCME WQI) and Bascarón water quality index (BWQI) are mentioned in Table 1.

Results and discussion

Water quality

The water quality index for the river was calculated from eleven parameters, namely: BOD, TDS, pH, DO, turbidity, PO_4, NO_3, chlorides, TH, EC, and alkalinity for eleven sampling stations to assess the suitability of lake water for general purposes. The descriptive statistics of the eight physicochemical and one biological parameter of water quality with their observed standard deviations for each site were calculated by three WQI methods as shown in Tables 2, 3 and 4.

The pH, temperature and total solids values of one unit each (S9, S1 and S9, respectively) out of eleven sampling points in the lake was within the limits of WHO standards. Turbidity values of three points (S3, S7 and S8) and DO values of four points (S1, S5, S6 and S9) out of eleven sampling points were below the permissible limit of WHO standards. Total phosphates values of five (S4, S5, S7, S10 and S11) out of eleven sampling points were within the permissible limits of WHO (Table 2). Total dissolved solids, electrical conductivity, chlorides, total suspended solids and nitrates values of eleven sampling points were within the permissible limits of WHO standards. Total alkalinity, BOD5 and COD values of eleven sampling points were above the permissible limits of WHO standards.

Water quality index

Weighted arithmetic water quality index

All the parameters above WHO guidelines can influence the weighted arithmetic index, but the parameters far above and far below the guidelines influence the index more. The weighted arithmetic water quality index results were more influenced by total alkalinity, BOD_5 and COD parameters (Table 3) than other quality parameters. This indicates the Hawassa Lake was contaminated by organic matter. The amounts of BOD5 and COD were high due to the amount of waste draining from domestic area, commercial area, medical centre and small-scale industries. The DO results were very low at sampling sites S1, S5, S6 and S9 than the WHO permissible limit of 5 mgl^{-1}. As per the EPA, temperature and DO have inter-influential parameters. Hawassa Lake was having an average temperature of 20.89 ℃. At this temperature, surface water should have the DO value of 9.0–9.2 mg/l (EPA, 2001). If the concentrations of microorganism and aquatic plants (algae) are high in water, they will reduce the amount of dissolved oxygen from the water body. Dissolved oxygen is consumed by aquatic life and indicated by CBOD and SBOD life.

The result of weighted arithmetic WQI which is the cumulative result of each water quality parameter was poor. As per the rating scale, this water body was polluted and it could not be used without treatment for any purpose. The status of water quality of Hawassa Lake calculated by WQI method (Table 3) was further confirmed by modified Bascarón water quality index method (Table 4) as well as Canadian Council of Ministers of the Environment (CCME) water quality index method (Table 5).

Table 1 Water quality indices and scales

Weight arithmetic water quality index		Canadian Council of Ministers of the Environment water quality index		Bascarón water quality index	
Water quality index value	Rating of the water quality	Water quality index value	Rating of the water quality	Water quality index value	Rating of the water quality
0–25	Excellent	95–100	Excellent	90–100	Excellent
26–50	Good	80–94	Good	71–90	Good
51–75	Bad	60–79	Fair	51–70	Medium
76–100	Very bad	45–59	Marginal	26–50	Bad
> 100	Unfit	0–44	Poor	0–25	Very bad

Table 2 Hawassa Lake water quality results in both dry and wet seasons at 11 sampling points

Station	Period	Temp	PH	Do	TDS	Turb	COD	TP	BOD	TA	EC	Chloride	TS	TSS	NO3
Station 1	dry	18.80	8.79	3.66	420	5.0	240	0.533	72.73	360	909	31.95	591	171	5.5
	wet	19.80	8.87	4.40	447	5.5	174	0.348	49.38	419	848	17.97	585	165	5.1
Station 2	dry	20.80	8.99	6.56	418	4.0	216	0.595	65.45	325	899	34.90	594	176	5.5
	wet	19.65	9.07	4.88	447	6.8	180	0.338	60.36	385	857	36.94	588	170	5.1
Station 3	dry	21.20	9.09	7.40	415	4.0	200	0.636	60.61	340	898	30.94	599	184	5.4
	wet	20.85	9.29	4.62	438	5.5	120	0.149	48.00	432	847	49.91	593	178	5.0
Station 4	dry	20.10	9.03	6.99	407	5.0	160	0.390	48.48	310	890	34.90	587	180	7.3
	wet	20.65	9.18	6.26	435	7.0	128	0.279	43.44	351	819	27.44	595	180	6.9
Station 5	dry	21.00	8.89	3.39	490	4.0	216	0.431	65.45	235	887	32.90	587	97	9.4
	wet	21.05	9.15	6.27	443	7.0	160	0.405	53.53	355	917	15.68	591	136	9.0
Station 6	dry	20.30	8.38	1.80	426	16.0	160	0.574	48.48	320	890	33.90	612	186	9.8
	wet	20.90	9.26	4.85	476	8.5	132	0.211	52.80	390	791	20.32	606	182	9.4
Station 7	dry	21.00	9.34	6.50	476	3.0	166	0.256	50.30	434	878	35.90	634	228	4.5
	wet	21.10	9.19	7.32	447	4.0	179	0.448	59.15	387	881	33.47	628	205	4.1
Station 8	dry	21.40	9.09	7.47	406	5.0	284	0.595	86.06	260	880	33.90	565	133	3.8
	wet	21.25	9.21	6.79	447	4.0	152	0.510	51.11	377	832	18.81	433	159	3.4
Station 9	dry	20.10	7.14	1.41	168	13.0	184	0.923	55.76	120	311	37.90	312	144	3.0
	wet	21.05	8.47	3.66	298	8.0	156	0.216	62.40	260	353	47.71	492	166	2.6
Station 10	dry	21.40	9.00	6.55	436	8.0	216	0.451	65.45	210	895	38.90	683	247	8.9
	wet	20.90	9.17	6.58	447	5.0	123	0.392	37.72	349	880	33.97	628	219	8.5
Station 11	dry	21.50	8.89	5.06	416	4.0	160	0.431	48.48	217	876	35.90	585	169	5.5
	wet	20.90	9.01	6.37	470	6.0	140	0.357	48.24	355	851	30.03	578	160	5.1

Table 3 Weighted arithmetic water quality index results

Sample	WHO	Unit weight	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Temp	20.0	0.0175	19.47	20.73	21.07	20.50	20.77	20.70	20.87	21.37	20.50	21.47	21.63
DO	5.0	0.0700	4.15	6.05	6.41	6.34	4.26	2.38	6.31	6.78	2.23	6.56	5.32
TDS	1000.0	0.0003	438.00	437.33	411.67	427.00	484.00	444.67	479.00	431.67	178.47	454.67	456.67
PH	8.5	0.0412	8.85	9.07	9.16	9.13	9.03	8.68	9.33	9.20	7.31	9.12	8.93
EC	1500.0	0.0002	868.33	871.00	864.00	796.00	907.33	824.33	880.33	848.33	339.00	885.00	859.00
Turb	5.0	0.0700	5.33	5.50	4.67	6.67	6.00	12.83	3.00	4.83	12.67	6.33	5.33
TA	120.0	0.0029	419.00	367.50	362.50	350.50	309.50	345.00	434.00	337.50	127.50	299.50	308.50
BOD5	5.0	0.0700	50.25	49.45	38.65	32.65	60.25	48.25	41.85	33.60	42.65	35.45	61.45
COD	20.0	0.0175	196.00	185.33	180.33	140.67	180.00	156.00	157.67	217.67	182.00	168.33	147.67
TP	0.50	0.6998	0.53	0.59	0.64	0.39	0.43	0.57	0.26	0.59	0.92	0.45	0.43
Chloride	250.0	0.0014	22.63	36.26	43.59	26.29	21.42	24.84	34.28	23.84	44.44	35.61	31.98
TS	500.0	0.0007	591.00	594.00	599.00	587.00	587.00	612.00	634.00	565.00	312.00	683.00	585.00
TSS	500.0	0.0007	171.00	176.00	184.00	180.00	97.00	186.00	228.00	133.33	143.60	247.00	169.00
NO3-	45.0	0.0078	5.54	5.51	5.40	7.28	9.44	9.84	4.47	3.84	3.02	8.87	5.50
ΣWn		1.0000											
Σqn*Wn			182.62	183.70	172.79	129.21	175.99	186.68	120.06	163.42	228.29	143.70	173.88
WQI			**182.62**	**183.70**	**172.79**	**129.21**	**175.99**	**186.68**	**120.06**	**163.42**	**228.29**	**143.70**	**173.88**
Status			Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit

Table 4 Modified Bascarón water quality index

Sample	WHO	Unit weight	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Temp	20.00	3.63	19.47	20.73	21.07	20.50	20.77	20.70	20.87	21.37	20.50	21.47	21.63
Do	5.00	4.70	4.15	6.05	6.41	6.34	4.26	2.38	6.31	6.78	2.23	6.56	5.32
TDS	1000	4.11	438	437.33	411.67	427.00	484.00	444.67	479	431.67	178.467	454.67	456.67
PH	8.50	4.55	8.85	9.07	9.16	9.13	9.03	8.68	9.33	9.20	7.31	9.12	8.93
EC	1500.00	3.90	868.33	871	864.00	796.00	907.33	824.33	880.33	848.33	339.00	885.00	859.00
Turb	5.00	4.65	5.33	5.50	4.67	6.67	6.00	12.83	3	4.83	12.67	6.33	5.33
TA	120	3.58	419	367.50	362.50	350.50	309.50	345	434	337.50	127.50	299.50	308.50
BOD5	5	4.63	50.25	49.45	38.65	32.65	60.25	48.25	41.85	33.60	42.65	35.45	61.45
COD	20	4.42	196	185.33	180.33	140.67	180.00	156	157.67	217.67	182.00	168.33	147.67
TP	0.50	4.21	0.53	0.595	0.64	0.39	0.43	0.57	0.26	0.59	0.92	0.45	0.43
Chloride	250	3.1	22.63	36.26	43.59	26.29	21.43	24.84	34.28	23.84	44.44	35.61	31.98
TS	500	3.75	591	594	599.00	587.00	587.00	612	634	565.00	312.00	683.00	585
TSS	500	4.21	171	176	184.00	180.00	97.00	186	228	133.33	143.60	247.00	169
NO3-	45	4.75	5.54	5.51	5.40	7.28	9.44	9.84	4.47	3.84	3.02	8.87	5.5
$\sum$CiPi			**56.93**	**49.80**	**57.21**	**50.39**	**49.67**	**51.78**	**49.83**	**50.54**	**56.40**	**49.58**	**57.31**
WQI			**32.41**	**32.69**	**32.73**	**33.09**	**31.95**	**26.81**	**32.90**	**33.82**	**31.8066**	**31.92**	**32.85**
Status			Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad

Modified Bascarón water quality index

The modified *Bascarón* water quality index results were influenced by the weightage as well as the sensitivity of the parameters. The parameters that have values far above and far below the WHO standards, influenced the index value more. The sensitivity parameters, viz., total alkalinity, BOD5, and COD, were highly influenced to finalize the quality of Hawassa Lake (Table 4).

Canadian council members of environment water quality index

The Canadian Council Members of Environment water quality index results were influenced by failed parameters at each sampling period. Each station has 14 total variable and 42 total tests. The minimum failed parameters were 17 at station 9, covering 40% of the total test, and the maximum failed parameters were 23 at station 6 covering 54% of the total tests (Table 5). So the failed parameters from the total tests averaged 45.89%. This might be the reason for the total water quality index to be marginal to poor.

Assessment of water quality indices

As per the previous studies (Kachroud et al., 2019), there was discrimination among the water quality indices. In this study, three different water quality indices, viz., weight arithmetic, Canadian Council Members of Environment and Bascarón water quality index methods, were used to understand the discrimination of the results of water quality indices (Fig. 2). As per the results, there was no discrimination found in the results of weighted arithmetic and Bascarón index methods due to their weightage and sensitivity, which are most important to justify the quality of water in the water body (Fig. 3). The Canadian Council Members of Environment method gave results close to the results of weighted arithmetic and Bascarón methods. CCME index results are marginal as these were influenced by the number of failed parameters. Accordingly, this index based on failed parameters did not justify being accurate method.

Secchi depth

Secchi depth measuring the visibility level of the lake is an ideal indicator of eutrophication level of the lake. The clarity of water depends on the concentration of total solids and the colour of the water body. The colour of the water sample is more intense in a eutrophic lake. Figure 4 shows Secchi depth to be 2.06 m where the depth of the lake was 25.8 m. The Secchi depth was very high at peripheral zones and very low in central zones. That meant, the eutrophication of the lake was higher in the central than peripheral zones. As per Lisa Smith et al. (2006), the Secchi depth of < 1, 1–2, 2–4, and > 4 represents the hypertrophic, mesotrophic, eutrophic, and oligotrophic states of the lake, respectively. The Hawassa Lake was in eutrophic state at central zone.

Eutrophication

Secchi depth, measuring the visibility level of the lake, is an indicator of eutrophication level of the lake. The light

Table 5 CCME water quality index

Station	F1	F2	F3	CCME WQI	WQI category	Sum of failed tests	Normalized sum of excursion	Total samples	Total variables	Actual variables tested	Total tests	Number of failed tests	Number of passed tests	Number of less than detected
Station 1	57.1	42.9	57.8	46.9	Marginal	57.6	1.4	3	14	14	42	18	24	0
Station 2	57.1	42.9	58.4	46.7	Marginal	58.9	1.4	3	14	14	42	18	24	0
Station 3	57.1	50	53.3	46.4	Marginal	47.9	1.1	3	14	14	42	21	21	0
Station 4	57.1	47.6	52.1	47.6	Marginal	45.7	1.1	3	14	14	42	20	22	0
Station 5	57.1	45.2	56.4	46.8	Marginal	54.4	1.3	3	14	14	42	19	23	0
Station 6	57.1	54.8	55.4	44.2	Poor	52.2	1.2	3	14	14	42	23	19	0
Station 7	50	45.2	55.7	49.5	Marginal	52.7	1.3	3	14	14	42	19	23	0
Station 8	50	42.9	57.9	49.4	Marginal	57.8	1.4	3	14	14	42	18	24	0
Station 9	57.1	40.5	58.6	47.3	Marginal	59.4	1.4	3	14	14	42	17	25	0
Station 10	50	45.2	51.2	51.1	Marginal	44.1	1	3	14	14	42	19	23	0
Station 11	64.3	47.6	51	45.2	Marginal	43.8	1	3	14	14	42	20	22	0

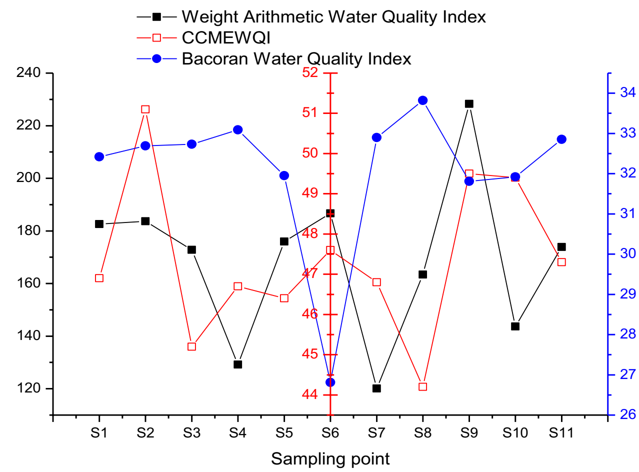

Fig. 2 Assessment of Three water quality indices

transmission in the lake or water body decreases because of the pollutant present in the system like solids and colour of the lake. The Secchi was less due to impurities of the lake arising due to lot of aquatic plants and algae growth on the water. Based on the concentrations of the nutrient (phosphate and nitrate) chlorophyll-a and Secchi depth, the lake could be categorized in the hypertrophic state. The inflow of sediment along with nutrients causes eutrophication of the lake. Dissolved organic matter in lakes would absorb light and alter the light environment at depth, which would subsequently affect phytoplankton growth (Li et al., 2017). Furthermore, industries housed in Hawassa Industrial Park (HIP) are known to release effluents into rivers and streams that end up into the swampy area of the Lake Shallo, from which River Tikurwhua originates (Zinabu et al., 2002) and feeds the lake. The water level of Hawassa Lake is increasing and the depth of water decreases due to sedimentation and eutrophication (Fetahi, 2019; Steinberger et al., 2019).

Discussion

The temperature at sampling points S3, S8, S10 and S11 was above the permissible limit. S3 might be influenced by the inlet water of Tikurwuha River. The sampling point S8 may also be influenced by S11, which was agricultural runoff inlet area, to have high temperature than the permissible limit. Temperature exerts a major influence on biological activity and growth, has an effect on water chemistry and can influence water quantity measurements. The rate of chemical reactions generally increases at higher temperature. Warm water holds less dissolved oxygen than cool water and may not contain enough dissolved oxygen for the survival of different species of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures.

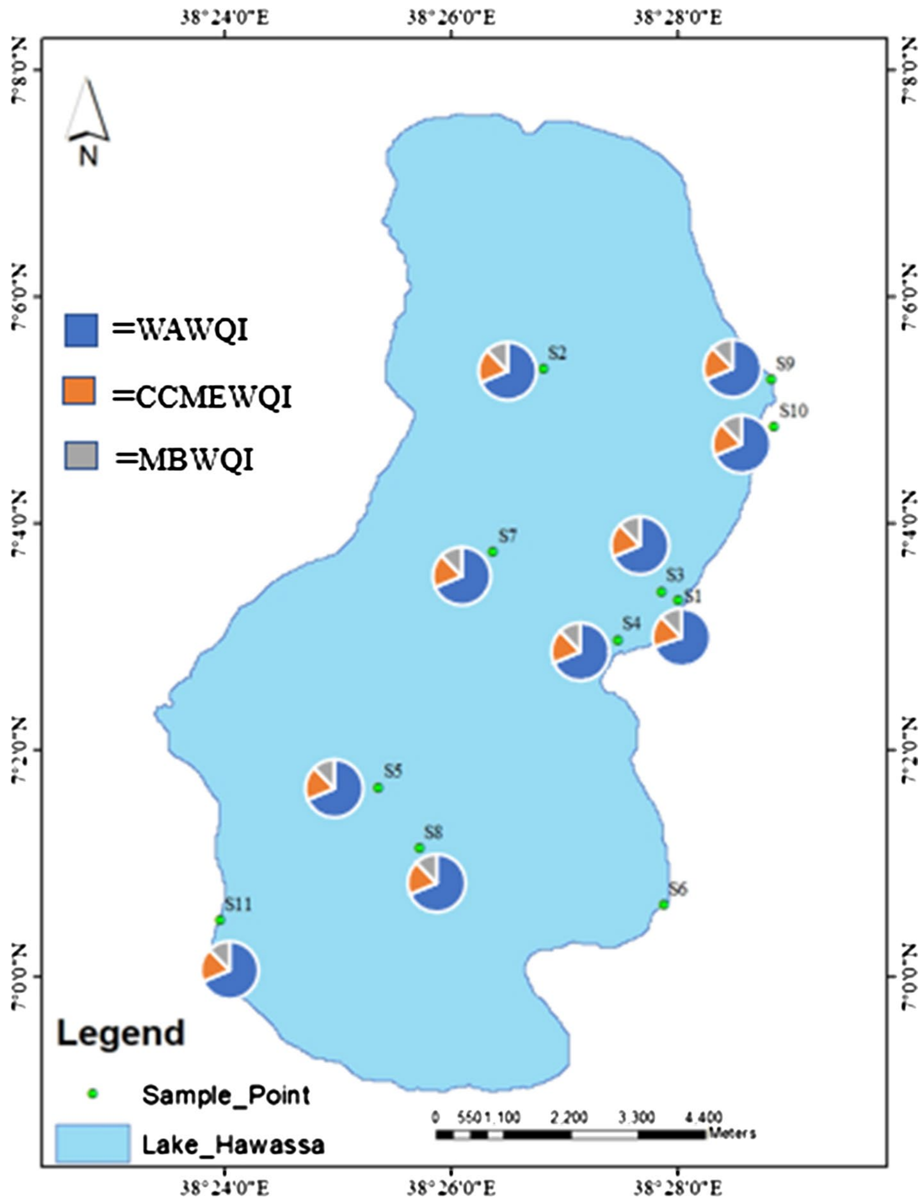

Fig. 3 Sampling points with water quality indices

The dissolved oxygen (DO) levels were below the acceptable limit of WHO at sampling points S1, S5, S6 and S9. The sampling point S1 has recreational and boating station as well as Fiker Hick (Love Lake) area, which caused dumping of food waste into the Lake. The decomposition of dumped food might be the reason for the low DO of the lake. Decomposition of submerged plants also contributes to low dissolved oxygen (Bojarczuk et al., 2018). Sampling points S5 and S6 are located near to the Hospital and urban agricultural area. Hospital drainage disposal into the lake as well as urban agricultural runoff might be the reason for the presence of low dissolved oxygen, i.e. 4.26 and 2.38, respectively. Sampling point S9 is the Inlet of Tikurwuha River, which is passing through the Cheleleka wetland. The urban drainage joining into the river at different segments of the river stream might be the reason of low dissolved oxygen content. Low dissolved oxygen primarily results from the presence of excessive nutrients in the lake. Due to this low dissolved oxygen fish survival is in danger. Each type of fish living in the water requires a different amount of dissolved oxygen to live. If dissolved oxygen levels decrease to about 3–4 mg/L, even the strongest fish may suffocate (Franklin, 2014).

The pH values are above the permissible limit at sampling points S2, S3, S4, S5, S7, S8 and S10 and indicate their alkaline nature. The pH levels may increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate

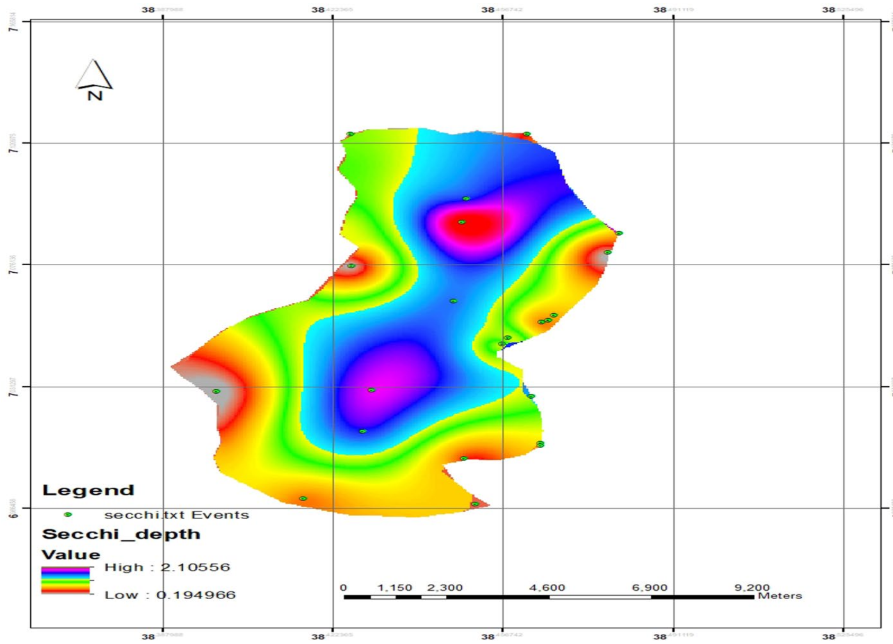

Fig. 4 Bathymetry expression Secchi depth of Lake Hawassa

nutrient related problems. The pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

Turbidity results are higher than the acceptable limit at sampling points S4, S5, S6, S9 and S10. The turbidity of sampling point S6 was 12.83 NTU, which was very high than the permissible limit. The higher turbidity might be due to discharge of hospital liquid waste as well as entering of urban agricultural runoff. The turbidity at sampling point S9 was 12.67 NTU, which was higher than the acceptable limit. The wetland and urban drainage may be the reason for the increase. The samples from S6 and S9 stations were murkier than S4, S5 and S10 stations. The major source of turbidity in the open water zone of most lakes is typically runoff water (soil erosion), industrial wastewater discharge, increased flow rate and flood waters in the lake Hawassa (Bhateria and Jain 2016).

Total solids were also above the limit at all sampling points, except sampling point S9. The sampling point S9 had TS close to the permissible limit, as it was the inlet of the Tikurwuha river stream. High levels of turbidity or total solids in water can be caused by many environmental factors. These include soil erosion, waste discharge, runoff, or changes in ecological communities. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates) and some small amounts of organic matter that are dissolved in water. Dissolved solids refer to any minerals, salts, metals, cations or anions dissolved in water.

Total alkalinity, BOD5 and COD values were above the permissible limit at all sampling points. According to Abate (2015) also BOD and COD concentrations were very high in the Lake Hawassa. Urban drainage discharges (detergents and soap-based alkaline products), resorts, recreational activities, hospital drainage discharge, agricultural runoff water, industrial wastewater (textile) and wetland area might be the reason for increase in the alkalinity of the lake.

Conclusion

The Hawassa Lake water quality was poor as per the weighted arithmetic and modified Bascarón methods, whereas it was marginal as per the Canadian Council Members of the Environment method. The normal depth of the lake was 25.8 m in the centre of the lake and Secchi depth was 0.3–1.9 m in peripheral zone up to 80 m from the shore. The sediment inflow (soil erosion), urban wastewater, industrial effluents inflow, resorts wastewater, hospital drainage water and agricultural runoff caused nutrient enrichment of the lake leading to its eutrophication and growth of floating plants in the lake. Based on the Secchi depth, the eutrophication status of the lake could be categorized as hypertrophic stage. The WQI and Secchi depth results correlated with each other, confirming that the quality and health of the lake was poor. Water resources authorities should take appropriate and quick action to control the inflow of wastewater as well as runoff and sediment from agricultural fields into the lake Hawassa to conserve its water resource.

Authors contributions ZM was involved in data collection and analysis of the water samples and mapping. BM was involved in research plan of Secchi depth (Eutrophication) and manuscript editing and review of manuscript. DR was involved in research plan of water quality indices and eutrophication, manuscript preparation, data analysis and interpretation of results.

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Compliance with ethical standards

Conflict of interest No conflict of interest.

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