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Water Quality and Trophic Status of Lake Ziway, Ethiopia, determined with contrasting methods and models

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ABSTRACT: The published literature on Lake Ziway report disparate data on its water quality and trophic status. This study aimed to determine the current water quality and trophic status of Lake Ziway using recent approaches and extensive sampling regimes. Water and bacteriological samples were collected from seven sampling sites for five months from April to August 2017. Physico-chemical parameters such as DO, EC, pH, and temperature were measured in situ with a portable multimeter probe. Nutrients were determined following the standard procedures of APHA. Total coliform was determined by spread plate technique and fecal coliform with membrane filter method. Water quality was computed with weighted arithmetic Water Quality Index method. Trophic status was calculated with Carlson index, and other two indices developed for tropical reservoirs (Lamparelli and Cunha et al.). Results indicated significant spatial difference of physicochemical parameters. Nutrients such as NO_3 and TP varied between 0.37-0.18 mgL^{-1}, and 0.24- 1.32 mgL^{-1}, respectively. Chl a values ranged from 24.3 to 88.1 µgL^{-1} and turbidity from 71 – 550 NTU.. WQI value was above 100 and indicated poor WQ status. Based on different TSI models, the trophic status of Lake Ziway was determined as hypereutrophic (TSI > 59) from all seven sites. The present study concludes that Lake Ziway is hypereutrophic and not oligo- to eutrophic status as reported earlier and promotes the use of recent TSI models which consider only TP and Chl a data to determine TS. Urgent integrated water management is recommended for the sustainable use of this important freshwater lake in the rift valley.

Keywords/ phrases: Hypereutrophic, Total coliform, Tropical Lake, Turbidity, Water quality index

INTRODUCTION

Lake Ziway is one of the shallowest freshwater lakes in Ethiopia's central rift valley , and is utilized for a variety of developmental activities including fisheries, irrigated agriculture (commercial farming), tourism, livestock watering, vehicle washing, human sanitation, and more recently, floriculture farming (Getachew Beneberu & Seyoum Mengistou, 2009; Hayal Desta *et al.*, 2015; Brook Lemma & Hayal Desta, 2016; Dessie Tibebe *et al.*, 2020). Both the inflowing rivers (Meki and Katar) and the lake are perceived to be highly degraded due to abstraction and pollution activities, even as noteably school children (Hayal Desta *et al.*, 2015) and the community at large. Based on SWAT model, Takele Gadissa *et al.*, (2018) estimated that the sediment load carried from the catchment by the Meki and Ketar rivers will decrease the lake volume by 38%, The high sediment input into the lake is also a source of nutrient enrichment, especially Phosphorous (Dessie Tibebe *et al.*, 2020) and the lake was categorized as eutrophic earlier (Dessie Tibebe *et al.*, 2018) and recently as hypereutrophic (Tadesse Fetahi, 2019). Several hydrochemical and limnological studies on Lake Ziway have reported contrasting and often contradictory results regarding its water quality, eutrophication level and trophic status.. For example, Tenalem Ayenew and Dagnachew Legesse (2007) reported high levels of nutrients (P, N, Si) and observed trend of salinization trend in the Lake Ziway catchment. The water quality of the lake showed high TDS, flouride, sodium and silicate compared to the inflowing rivers (Hailu Gashaw 1999). In the work of Merga et al., (2020), several discordant results on nutrients, heavy metals and pesticides were reported for the lake, For instance, Orthophosphate values ranged across two orders of magnitude from low value of 10.2 (Tilahun & Ahlgren, 2010) to high value of 211 ug/l (Getachew Beneberu & Seyoum Mengistou 2009).

Reported Ammonium values were as low as 0.11 (Tilahun & Ahlgren, 2010) to high value of 1.02 mg// (Teklu et al., 2018). .Unusually high nitrate values of 12.7 mg/l, 42.3 mg/l and 56.6 mg/l were reported from different parts of the same lake (Teklu et al., 2018). However, based on the temporal variation of turbidity and Chl a, Getachew Beneberu and Seyoum Mengistou (2009) suggested that the lake was heading towards oligotrophication. In contrast both earlier and more recent studies had recorded that the lake was heading towards eutrophication status (Tenalem Ayenew and Dagnachew Legesse, 2007; Girum Tamire & Seyoum Mengistou, 2012; Teklu *et al.*, 2012; Dessie Tibebe, 2017; Dessie Tibebe *et al.*, 2018; Hayal Desta, 2021, Dessie Tibebe et al., 2022).

Part of the reason for such discrepancy on the water quality and trophic status of Lake Ziway can be attributed to several factors, including limited sampling, varying methodologies and approaches used by different investigators, although natural temporal variations in water quality are also to be expected. Besides, water quality data of previous workers (e.g. Hailu Gashaw 1999; Tenalem Ayenew and Dagnachew Legesse 2007) did not include bacteriological analysis , and relied solely on threshold values for nutrients (phosphorous and nitrogen) to infer the pollution condition at the time of sampling (Hayal Desta *et al.*, 2015). Sampling times were often limited to a few visits and comprehensive spatial and temporal time series data were not collected, with the exception of Dessie Tibebe et al., (2022) who sampled nine sites These limited data can lead to erroneous or controversial conclusion.

When inferring the trophic status of tropical lakes likes Ziway, there has been growing tendency to use indices developed for temperate conditions such as the Carlson trophic index (Carlson, 1977), which uses parameters of turbidity, algal biomass as Chl a and nutrients (Total Phosphorous (TP) and Total Nitrogen (TN))). However, the validity of the use of turbidity in the computation of this index has recently been questioned by tropical limnologists from South America. Lamparelli (2004) and Cunha *et al*., (2013) have suggested modified indices which primarily rely on Chla and TP values, and have demonstrated that these indices clearly differentiate the trophic status of tropical reservoirs which they studied. Considering that previous reports on the trophic status of Lake Ziway had used the Carlson index (Hayal Desta *et al.,* 2015; Dessie Tibebe, 2017; Dessie Tibebe *et al.,*2018; 2020 ; 2022; Hayal Desta, 2021), we opted to recalculate the trophic index of Lake Ziway based on the recommendations of Lamparelli (2004) and Cunha *et al*., (2013) because Lake Ziway equally qualifies for the ecological conditions which they discussed, and the earlier suggested oligotrophication trend was based largely on Chl a and turbidity. Many of these results on WQ and TSI were reported after our study in 2017; we wanted to publish this paper now so as to prevent further misrepresentation about the water quality and trophic state index of Lake Ziway, and to advocate the use of recent tropical models for determination of TSI in other Ethiopian water bodies in future.

We believe that our present approach gives a more realistic picture of the water quality and trophic status due to several reasons - we sampled the lake more intensively for 5 months and covered a wider section of the lake (7 sites) and also applied recent models of water quality and trophic state indices developed for tropical conditions (Lamparelli, 2004; Cunha *et al.*,2013). Thus our main objective is to report on the current ecological condition of Lake Ziway by using the most recent indices of water quality and trophic status, and resolve the inconsistent data about the ecological condition of the lake, and also recommend scientific evidence for management purpose.

MATERIALS AND METHODS

Study area

Lake Ziway lies 08° 01′ N and 38° 47′ E within Rift valley system at an altitude of 1636 m above sea level. Lake Ziway is one of the freshwater lakes from central rift valley, having a low salt concentration (0.349 g/l. Two main rivers, Meki from the north-west and Katar from the east-flow into the lake and it has an outflow through Bulbula River, draining into Lake Abijata (Fig. 1). The lake has a rich biodiversity of plankton, water birds, fish and hippopotamus. The fast-developing city of Batu (population of 49 416, 2021 census) is located on the southern edge of the lake.

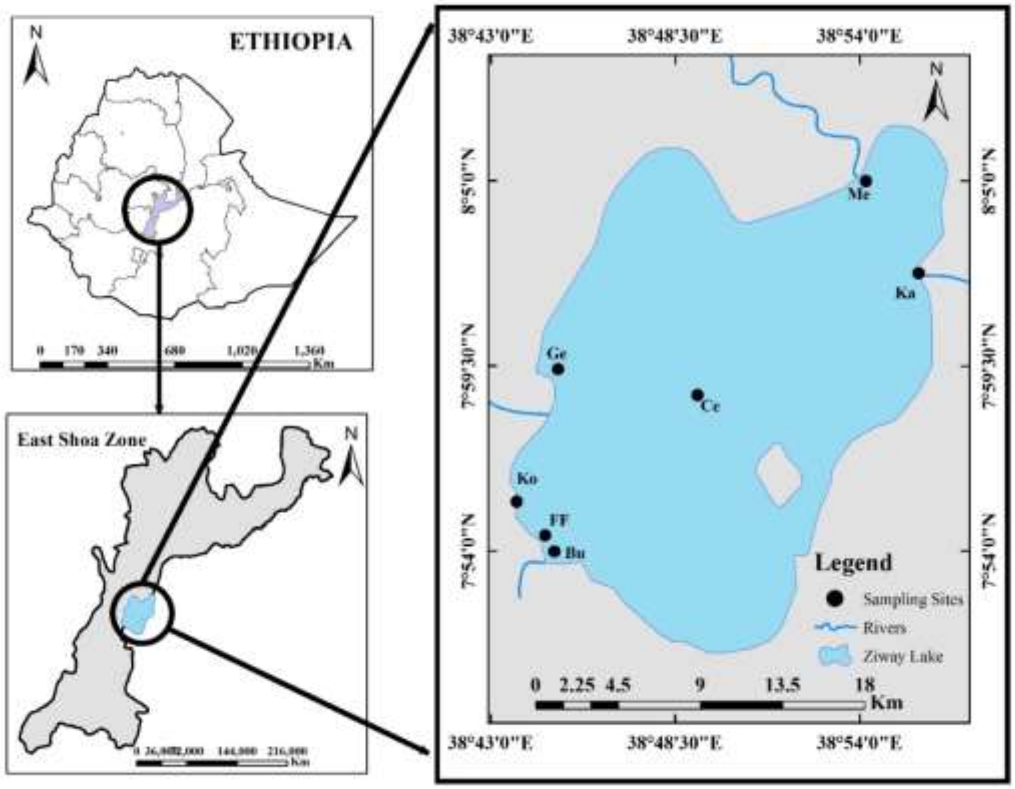

Figure 1. Map of Lake Ziway in the Ethiopian rift valley and sampling sites (shown as dots).

Water sampling and In situ measurements

Water samples were collected monthly from April 2017 to August 2017 – from seven selected sites based on their exposure to anthropogenic activities from outflow of the lake Ziway (Bulbula River), to the macrophyte dominated areas. Sites were marked with GPS coordinates and all parts of the lake were reached in this study. The months of late July and August represent the rainy season in the lake area. Composite water samples were taken from the surface and also at some depth profiles (surface 0.5m, 1m, 1.5m). Temperature, pH, dissolved oxygen (DO), Electrical conductivity (EC) was measured using HQ40d modal multimeter. Secchi disc depth (SDD) was measured with a Secchi disc of 20 cm diameter and turbidity was determined using OAKTON model turbidity meter. All the above parameters were measured *in situ* during the sample collection. Filtered composite water samples were taken from each sampling sites of the lake to Addis Ababa University Limnology laboratory for laboratory analysis of nutrients. Soluble reactive phosphorus (SRP) and Total phosphate (TP) were measured with the Ascorbic acid method and persulfate digestion for the latter (APHA 1999), Nitrate (NO_3) with Salicylate method (APHA 1995), Ammonium (NH_4) with phenate method (APHA, 1999). Faecal (FC) and Total Coliforms (TC) were analysed with the Membrane Filtration technique (0.45 µm) (APHA, 1998) and with spread plate techniques. (APHA, 1998). Chl a was determined as in Wetzel & Likens (2000)

Phytoplankton abundance and composition

Subsurface phytoplankton samples were taken with a Van Dorn sampler and preserved with Lugol's solution immediately after sampling and examined and enumerated with an inverted microscope. Identification to the level of the genus was done based on standard keys, such as Hindak (1992) and Gasse (1986). From the preserved subsample, 1ml phytoplankton sample was taken to the counting chamber or Sedgewick Rafter Cell and 30 up to 50 grids were counted to calculate the abundance of phytoplankton. The calculation was done using the following formula.

$$C\ [\text{cells mL} - 1] = \frac{N * 1000\text{mm3}}{A * D * F * \text{concenteration}}$$

Where,

$$\text{Concentration factors} = \frac{\text{the volume of lake water filtered}}{\text{volume of concentrate}}$$

N = number of cells counted
A = area of the grid (mm^2)
D = depth of a grid (Sedgwick-Rafter chamber depth) (mm)
F = number of grids counted.

Water quality index of Lake Ziway

WQI was determined using weighted arithmetic mean method (Brown *et al.*, 1970) by using the following equation.

$WQI = \sum QiWi/Wi$

$Qi = 100[(Vi - Vo/Si - Vo)]$ Where Vi is the estimated concentration of i th parameter in the analyzed water Vo *is* the ideal value of this parameter in pure water Vo= 0 (except pH =7.0 and DO = 14.6 mg/l) Si =is recommended a standard value of i th parameter for a certain purpose. The unit weight (Wi) for each water quality parameter is calculated by using the following formula:

Wi = K/Si

Where,

K = proportionality constant and can also be calculated by using the following equation:

$$K = \frac{1}{\sum 1/Si}$$

Water quality rating was interpreted according to the categories given in Table 1.

Table 1. Water Quality Rating as per Weight Arithmetic Water Quality Index Method.

WQI value	Rating of Water Quality
0-25	Excellent water
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
Above 100	Unsuitable for any purpose

Trophic Status of Lake Ziway

The trophic state index of Lake Ziway was computed according to Carlson (1977), Lamparelli (2004) and Cunha *et al.*, (2013); the last two models were developed for tropical/subtropical water bodies.

The Trophic State Index (TSIC) of Carlson (1977) which was developed for temperate environments and is a trophic state classification method based on total in-lake phosphorus concentration, in-lake Chlorophyll-a (Chl a) and water transparency (Z_{SD}).

- Secchi Disk Depth TSI **(TSI_{SD})**

TSISD = 60 - 14.41 ln Z_{SD} (m)

- Chlorophyll-a TSI **($TSI_{Chl\ a}$)**

$TSI_{Chl\ a}$ = 30.6 + 9.81 ln Chl a (µg L^{-1})

- Total Phosphorus (TP) TSI **(TSI_{TP})**

TSITP = 4.15 + 14.42 ln TP (µg L^{-1}), and combining the three parameters,

$$TSIC = \frac{TSITP + TSIchia + TSISD}{3}$$

TSIC values < 40 are classified as oligotrophic, 40-60 as mesotrophic, 60-80 as eutrophic and > 80 as hypereutrophic.

The Trophic State Index (TSI) of Lamparelli (2004) and (Cunha *et al.*, 2013) are trophic state classification methods based on means of total in-lake phosphorus concentration (TP) and Chlorophyll-a (Chl a), excluding turbidity, as in the following equations

$$TSILamp = \frac{TSI(TP) + TSI(Chl - a)}{2}$$

where

$$TSI(TP) = 10\left[6 - \frac{(1.77 - 0.42 * \ln TP)}{\ln 2}\right]$$

$$TSI(Chl - a) = 10\left[6 - \frac{(0.92 - 0.34 \times \ln Chl - a)}{\ln 2}\right]$$

Lamparelli (2004)

Cunha *et al*., (2013) proposed a new trophic state index for tropical/subtropical reservoirs (TSItsr) based on the annual geometric mean concentrations of TP and Chl a and proposed newer trophic state categories such as ultraoligotrophic, supereutrophic and hypereutrophic (Table 2).

$$\mathrm{TSItsr} = \frac{TSI(TP)tsr + \mathrm{TSI(Chl-a)tsr}}{2}$$

Where

$$\mathrm{TSI(Chla)tsr} = 10\ \left[6 - \left(\frac{-0.2512\ \ln \mathrm{Chl\ a} + 0.842257}{\ln 2}\right)\right], \text{and}$$

$$\mathrm{TSI(TP)tsr} = 10\ \left[\ 6 - \left(\frac{-0.27637\ \ln \mathrm{TP} + 1.329766}{ln2}\right)\right]\backslash$$

Table 2. Categories of the Trophic State Index (TSI tsr) for tropical and subtropical reservoir proposed by Cunha et al. (2013).

	Trophic state category	Chl a (ug/L)	Geometric mean, annual TP (ug/L)	TSItsr
1	Ultraoligotrophic	<2.0	<15.9	<51.1
2	Oligotrophic	2.1-3.9	16.0-23.8	51.2-53.1
3	Mesotrophic	4.0-10.0	23.9-36.7	53.2-55.7
4	Eutrophic	10.1-20.2	36.3-63.7	55.8-58.1
5	Supereutrophic	20.3-27.1	63.8-77.6	58.2-59.0
6	Hypereutrophic	>27.2	>77.7	>59.1

Statistical analysis

The relationships (correlations) among physicochemical and biological parameters were assessed using statistical software (SPSS Version 20) at 95 % confidence limit. Spatial variations of measured physicochemical parameters were analysed using one-way Analysis of Variance (ANOVA). The relationship between the abundance of taxa of phytoplankton and physicochemical variables was assessed with Redundancy Analysis (RDA), using CANOCO for Windows version 4.5. Detrended Correspondence Analysis (DCA) was run because the length of the longest gradient was less than 3 and the species data show linear response to environmental variables. Excel and Sigma plot version 10 were used for the graphs.

RESULTS AND DISCUSSION

Physicochemical parameters

Data for the physicochemical parameters of Lake Ziway along the sampling sites are presented in Table 3. Most values of the physicochemical parameters showed significant variation among the sampling sites.

Table 3. Mean values of physicochemical parameters among seven sampling sites in Lake Ziway.

	Sites						
Parameters	Center	Bulbula	Meki	Katar	Gebriel	Flower Farm	Korokonch
pH	8.94^{ab}	8.93^{ab}	8.22^{a}	8.64^{ab}	8.92^{ab}	8.91^{ab}	8.96^{b}
Temperature, ^{o}C	22.77^{ab}	25.09^{bc}	22.93^{ab}	23.67^{abd}	21.75^{a}	25.39^{cd}	24.97^{bd}
Conductivity, µScm^{-1}	295.9^{ab}	219.5^{b}	277.6^{b}	389.9^{a}	219.1^{b}	293.1^{ab}	220.2^{b}
Turbidity, NTU	194.30^{a}	189.25^{a}	549.55^{b}	515.85^{b}	173.48^{ac}	71.36^{c}	161.18^{ac}
DO, mgL^{-1}	7.20^{ac}	7.93^{a}	6.56^{cde}	6.77^{cde}	6.31^{be}	7.10^{cde}	7.35^{ad}
Chl a, µgL^{-1}	24.3a	40.7a	88.1a	25.3a	31.4^{a}	25.6^{a}	32.3^{a}
Nitrate (NO_3), mgL^{-1}	0.18^{a}	0.18^{a}	0.19a	0.23^{a}	0.18a	0.37^{b}	0.18a
NH_4, mgL^{-1}	0.08^{ab}	0.10^{a}	0.06^{bc}	0.06^{ac}	0.07^{ac}	0.06^{ac}	0.10^{ac}
PO_4^{3-}, mgL^{-1}	0.09^{ab}	0.10^{a}	0.09^{ab}	0.11^{ab}	0.08^{ab}	0.08^{ab}	0.15^{b}
TP, mgL^{-1}	0.42^{a}	0.28^{a}	1.32^{b}	1.31^{b}	0.24^{a}	0.31^{a}	0.27^{a}
TDS, mgL^{-1}	233^{a}	222^{a}	217^{a}	216^{a}	234^{a}	236^{a}	231^{a}
SDD, m	0.14	0.19	0.12	0.11	0.15	0.18	0.16

NB: Means within a column followed by the same letter are not significantly different (p>0.05)

The present study indicated that the concentration of DO fluctuated between 6.31 mgL^{1}at Gebriel sites to 7.93 mgL^{-1} at Bulbula sampling site with the mean concentration of 7.3 mgL^{-1}and the lowest DO value was recorded in August. USEPA (2005) defined the value of DO for healthy water to be within the range of 5−14.6 mgL^{-1} and less than 5 or greater than 14.6 indicate the impairment of the water body. The value of DO in all sampling sites is within the permissible limits of EPA (1993) and WHO (2004) (>5 mgL^{-1}) standards, which is suitable for aquatic life. Even though DO is within the permissible limits of different standards, the water of Lake Ziway is not conducive for aquatic life and drinking purpose due to other contaminants and chemicals coming from the surrounding.

The pH value of the present study varied between 8.22 and 8.96 (Table 2). The pH value of most rift valley lakes generally varied between 8 and 9. Based on WHO (2004) and APHA (1999), the optimal level of pH for both potable water as well as for the survival of aquatic organisms are within the range of 6.5-8.5. However, the present pH value of Lake Ziway was above the permissible limits except for Meki sampling site which is 8.22.

The mean value of surface water temperature in the present study was 23.8^{o}C, which is higher than the previous report 22.4^{o}C (Girma Tilahun and Ahlgren, 2009). Temperature varied between 21.75 – 25.39 ^{0}C and the difference of 3.6 ^{0}C is not expected to make noticeable difference in biological or chemical attributes of the lake, even though water temperature is the main controlling factor for different metabolic activities,

The mean Electrical Conductivity (EC, µS/cm) of Lake Ziway ranged from 219µS/cm to 390µS/cm and the overall mean value of all sampling sites was 274 µS/cm. All value of EC in the lake was below the recommended limits (1500 µS/cm, WHO, 1996) and (1000 µS/cm USEPA 19993) guidelines prescribed for drinking and another purpose. The present results are lower compared to the previous works 478 µS /cm (Girma Tilahun and Ahlgren ,2009) and 419 µS/ cm (Girum Tamire and Seyoum Mengistou, 2012). Most sampling sites did not show significant difference except Katar site. The overall mean value of electrical conductivity in Lake Ziway was 274µScm^{-1}

The mean value of turbidity (NTU) at Katar and Meki sampling sites showed significant variation (P=0.001). The minimum mean value was recorded at Flower farm site 71.36±15 and maximum mean values were recorded at Meki (549±27) and Katar (515.85) sampling sites. The catchment of Lake Ziway is highly degraded that facilitate erosion due to runoff during the rainy season (Dessie Tibebe, 2017). During the present study, the overall mean turbidity value was higher compared with the previous studies 42 to 70 NTU, (Girum Tamire and Seyoum Mengistou, 2012). The turbidity of Lake Ziway was beyond the recommended limits of both WHO (1984) and USEPA (2005) which is <5 for drinking water and also not suitable for aquatic flora and fauna. Furthermore, the higher turbidity affects primary productivity by restricting light penetration and intuitively influence photosynthesis ultimately affecting the base of the food web (Cunha *et al.,* 2013). Girum Tamire and Seyoum Mengistou (2012) have proposed that turbidity is one of the factors facilitating the proliferation of macrophytes around the lakeshores, where algal production was limited by the high turbidity.

The overall mean total dissolved solids (TDS) value during this study was 227 $mgL^{-1}$and most of the sampling sites had similar values. The present study is comparable with the mean value reported by Dessie Tibebe (2017) which is 263 mg L^{-1}. TDS value of Lake Ziway is categorized under a good water condition or palatable water (<600 mgL^{-1}, WHO 2011).

The overall mean Secchi Depth (SD) reading of Lake Ziway is 0.15m which is generally low. The lowest SD reading was observed at Katar and Meki sampling sites which was 0.12m and 0.11m, respectively. These two sampling sites had high turbidity values than other sampling sites. The overall SD reading was similar to the previous reports for the same lake (Getachew Beneberu and Seyoum Mengistou, 2009; Dessie Tibebe, 2017). Lower SD reading and high turbidity were associated with the rainy months of July – August because of high siltation from the surrounding agricultural land and different urban waste material through runoff and inflow of Meki and Katar rivers.

Ammonia Nitrogen ($NH_{3:}$ NH_4^+) concentration in Lake Ziway ranged from 0.08 to 0. 1 mgL^{-1} and showed significant variation among the sampling sites (P=0.001). The highest mean value of Nitrate ($NO_{3\text{-}N}$) was recorded at the Flower Farm sampling site (0.37±0.56 mgL^{-1}), followed by Katar sampling site (0.23±0.29). The mean value showed significant variation among the sampling sites (P=0.001). The overall mean concentration of $NO_{3\text{-}}$ in Lake Ziway was 0.22 mgL^{-1} and it is almost similar to the value (0.21 mg L^{-1}) reported by Dessie Tibebe (2017). However, the value of $NO_{3\text{-}}N$ in the present study is higher than other previously reported studies for the same lake, which were 0.003 mg L^{-1} and 0.06 mgL^{-1} by Girma Tilahun and Ahlgren (2009), and Girum Tamire and Seyoum Mengistu (2012), respectively. The high value of Nitrate in the present study might be associated with increasing of human activities around the water bodies and also in the water bodies. However Nitrate values were generally low in all the sampling sites and sampling seasons and fell within the WHO permissible standard of 50 mgL^{-1} for drinking water (WHO, 2004). On the other hand, the total mean concentration of NH_3-N (0.08±0.04) was relatively lower than the results reported 0.14 mgL^{-1} Girum Tamire and Seyoum Mengistou (2012) and 0.11 mg L^{-1} Girma Tilahun and Ahlgren (2009).

The overall mean SRP value of the present study was 0.1 $mgL^{-1}$and most of the sampling sites had similar concentration of SRP value or it did not show a significant difference among the sampling sites and periods. The mean SRP values are higher than the previous reports 0.035 mg L^{-1}, (Zinabu Gebre-Mariam, 2002); 0.029 mg L^{-1}, Girum Tamire, and Seyoum Mengistou, (2012); and 0.06 mg L^{-1}, Dessie Tibebe (2017). Similarly, the mean TP value of L. Ziway ranged from 0.24 to 1.32 mg L^{-1}, TP value showed a significant difference among the sampling sites. In particular, Meki and Katar sampling sites showed higher values than other sites. The higher TP at Katar and Meki sampling sites could be due to high runoff from Katar and Meki rivers as the sampling period was during a rainy season where most agricultural activities are taking place. The catchment of Lake Ziway is agriculture-intensive, deforested and highly degraded by different human activities.

The elevation of SRP and TP concentration from time to time was related to the habitat degradation of the watershed and poor land use management. The lake side's protected macrophytes and trees around the shore are being heavily cleared by the lakeside communities for different purposes (e.g., house roofing, making rafts), knowing the status of the plants is crucial for wise use of these resources (Girum Tamire and Seyoum Mengistou 2014). The algal nutrient concentration is high particularly in Meki and Katar sampling sites that are tributaries of the lake. Phosphorus concentration greater than 0.3mgL^{-1} indicates anthropogenic disturbance (USEPA, 2005). On the other hand, the mean TP value categorized Lake Ziway as hypereutrophic. In fact, TP > 0.13 mgL^{-1} is generally grouped under hypertrophic condition (Lau *et al*., 2002).

The mean value of SRP concentration ranged from 0.08 to 0.15 mgL^{-1} highest value was recorded at Korkonch site (0.15±0.02). However, the variation in concentration of SRP was not significant among sampling sites. But The mean value of Total Phosphorous (TP) concentration also ranged from 0.24±21 mgL^{-1} at Gebriel to 1.32±0.15 mgL^{-1} at Katar, and the mean concentration value showed significant variation among the sampling sites (P=0.001). The overall mean concentration of TP in mg^{-1} was 0.59±0.036 mgL^{-1}.

Total Dissolved Solids (TDS) ranged from 216 mgL^{-1} at Katar to 236 mgL^{-1} at flower farm sampling sites. The other sampling sites did not show significant difference. The highest TDS value was recorded at the flower farm site which could be due to the chemicals used in the greenhouses.

Biological parameters

Bacteriological data

The bacteriological load of Lake Ziway did not show significant difference among all the sampling sites ($p>0.005$; Fig. 2). However the maximum TC bacteria was observed at Korkonch and Meki sampling sites, which may be associated to waste materials that emanate from Ziway town and Meki River. The lowest FC coliform bacteria count was observed at Gebriel sampling site, which is dominated by macrophyte vegetation that might have trapped bacterial load. The present TC and FC concentrations were lower than the previous report of Mekuria Mekonnen *et al.*, (2014).

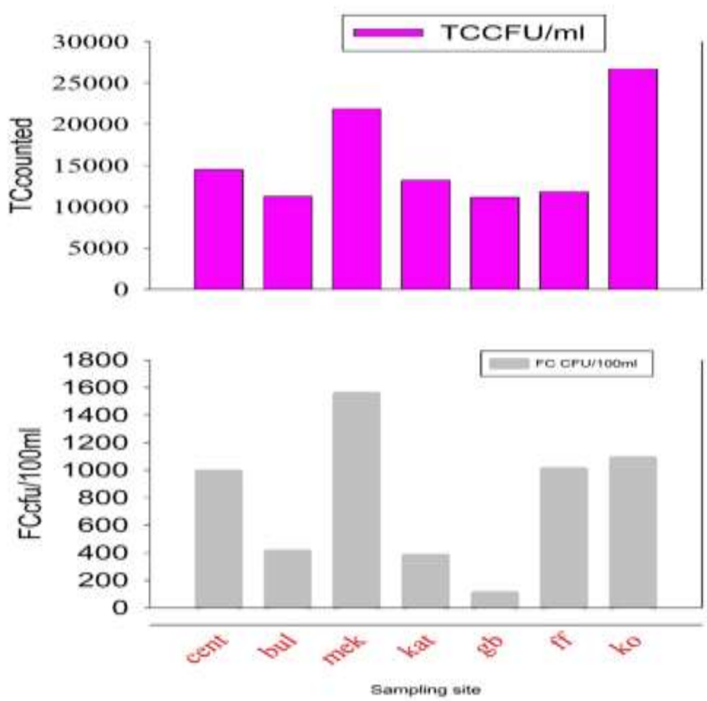

Figure 2: Bacteriological load (counts/ml) for the seven sites in Lake Ziway.

Phytoplankton composition and biomass

In the present study, a total of 31 phytoplankton taxa were identified and the phytoplankton taxa composition was comprised of 10 taxa of Bacillariophyta, 9 taxa of Chlorophyta, 8 taxa of Cyanophyta, 3taxa of Euglenophyta, and 1 taxon of Cryptophyta (Table 4).

The concentration of chlorophyll-a ranged between 24.3μgL^{-1} and 88.1 μgL^{-1} with an average value of 38.2 μgL^{-1}. These variations may occur due to the high spatial variation and abundance of phytoplankton in the lake. This finding was comparable to the result reported by Girma Tilahun and Ahlgren (2009) and Dessie Tibebe , (2017) which is 39.2 μgL^{-1} and 42 μgL^{-1}, respectively. The trophic state of L.Ziway using phytoplankton biomass alone would be categorized as supereutrophic and hypereutrophic condition, based on tropical and subtropical trophic state models.

Table 4. Major taxa of phytoplankton identified in Lake Ziway during this study.

CYANOPHYTA Blue-green algae	BACILLARIOPHYTA Diatoms	CHLOROPHYTA Green algae	EUGLENOPHYTA	CRYPTOPHYTA
Microcystis.spp.	*Aulacoseira spp.* *Aulacoseira granulata*	*Pediastrum spp* *Pediastrum duplex* *Pediastrum simplex*	*Phacus acuminutus* *Phacucs longicauda*	*Cryptomonas sp.*
Lyngbya sp.	*Navicula spp.*	*Scenedesmus spp.*	*Trachelomonas spp.*	
Anabaena spp.	*Cymbella spp.*	*Actinastrum spp.*		
Merismopedia spp.	*Synedra spp.*	*Closterium spp.*		
Cylindrospermopsis *spp.*	*Cycllotela*	*Ankistrodesums spp.*		
Pseudoanabaena sp.	*Fragillaria spp.*	*Cosmarium spp.*		
Chroococcus sp	*Surirella spp.*	*Oocystis spp.*		
	Pinnularia spp.	*Staurastrum sp.*		
	Nitzschia spp. *Asterionella spp.*	*Coelastrum sp.*		

Phytoplankton abundance counted and calculated for seven sampling sites within five months sampling periods indicate that diatoms were the most dominant groups compare to other groups of phytoplankton, primarily due to the high number of *Aulacoseria spp*. Bacillariophyta contributed around 65.6% to the total phytoplankton taxa, followed by Cyanophyta (18.5%), Chlorophyta (13.6%), Euglenophyta (1.33%) and Cryptophyta (1%). The latter two groups contributed a very small percentage to the phytoplankton abundance.

Phytoplankton biomass measured as Chl a, varied both spatially and temporally (Fig. 3). The mean maximum Chl a value (88.1±71) was recorded at Meki sampling sites while the minimum mean value was observed at Center sampling site 24.3±3.4 μgL^{-1}. The overall mean value of Chl a was 38.2±10.6 μgL^{-1} for all sampling time and sampling sites of Lake Ziway.

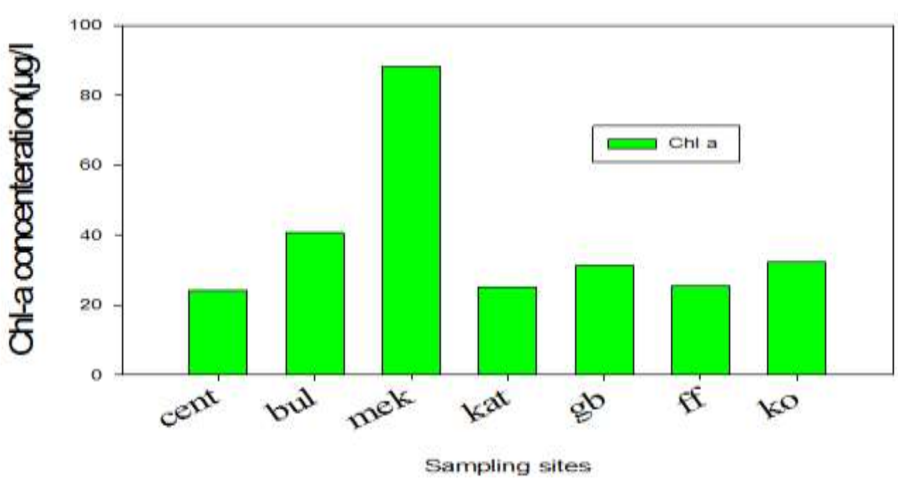

Figure 3: Phytoplankton biomass as Chl a in the seven sampling sites of Lake Ziway

Phytoplankton-Environment Relationships

The relationship between physicochemical variables and phytoplankton abundance is shown in the ordination plot (Fig. 4) The first axis accounted for 96% of the total variance of the species-environment interactions and was loaded with TP and turbidity factors and showed negative correlation with nutrients and TDS. Cyanophytes and diatoms were dominant under these environmental conditions and the river mouths sites (2, 3 and 4). The second axis accounted for 2.7% of the variance in species–environmental relationship and is positively correlated with Phosphate (PO_4-P), pH, Temp, K25, Turbidity and DO (Table 5). Cryptophytes and Euglenophytes were abundant in center site.

Table 5: Loading factors on the first two axes of RDA result showing relationship between environmental variables and phytoplankton abundance.

Parameter	Axis1	Axis 2
Eigenvalues	0.962	0.027
% variance of species environment Relation	96.2	2.7
pH	-0.83	0.0303
Temp	-0.3239	0.4888
K_{25}	0.5167	0.1858
Turbidity	0.953	0.1531
DO	-0.3013	0.4536
NO_3	-0.2829	-0.1749
Ammonia(NH_4-N)	-0.4114	0.4503
Phosphate(PO_4-P)	-0.122	0.9012
TP	0.9071	0.1609
TDS	-0.9366	-0.2471

From the above result, it can be concluded that the water quality and trophic state is highly influenced by environmental factors and the sampling sites**.** The major drivers for Cyanophyte and diatom abundance were turbidity and TP while for Euglenophyes and Cryptophytes it was SRP. Green algae were less correlated with the above factors.

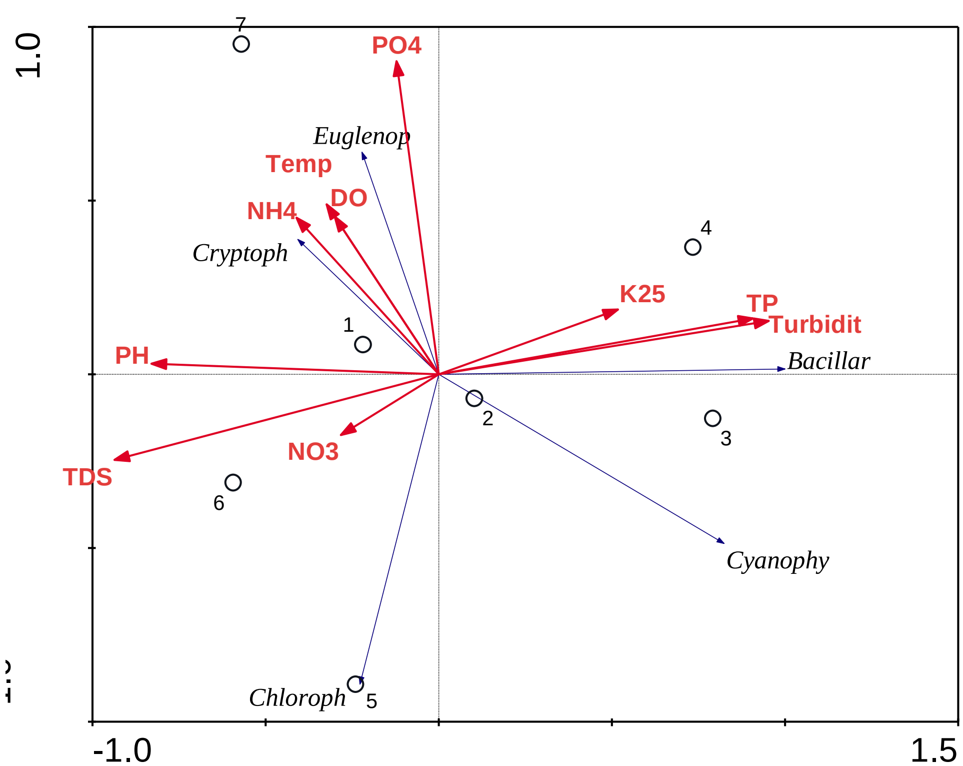

Figure 4. RDA triplot showing relationship between environmental variables, phytoplankton abundance and sites in Lake Ziway (7 sites coded as 1=Center, 2=Bulbula, 3=Meki, 4=Katar, 5=Gebrel, 6=Flower farm, 7=Korkonch. The environmental variables as in Table 1 and phytoplankton taxa as in Table 3).

WQI of Lake Ziway

The overall value of WQI in the present study was very high (393.3), even though site WQI values did not show significant variation among most of the sampling sites Table 6). The overall WQI value of each sampling sites was >100, and according to Toma *et al.* (2013), any value of WQI > 100 is unsuitable for drinking or any other purposes (see also Table 1). According to WHO (2004), the water quality of Lake Ziway is not suitable for drinking purpose, which is why water is pumped from the lake and treated in the Ziway Water Treatment Plant before release into the distribution system.. The extreme unsuitability of the lake water for any purpose might be related with poor waste disposal practice, the absence of waste treatment plant around industries and the release of waste direct into the lake. The absence of watershed protection and influx of agricultural pesticides into the lake through runoff and poor land use practice also contribute to the problem. The municipality of the town of Batu (former Ziway) has a water treatment plant to improve the quality of the water before release into the supply system. Hence, more research should be done on the water quality of household tap water to assess the efficiency of the treatment process. EPA needs to set rules and regulations for the industries to use proper treatment plant to minimize release of harmful chemicals to the water bodies.

Table.6 Water quality parameters and WQI of Lake Ziway based on weight arithmetic method (See the methods section for meaning of each unit).

Parameters	Observed (Vn)	Standard (Sn)	VI	1/Sn	K	Vn-Vi/Sn-Vi	Wn=K/Sn	Qn	Wn*qn	WQI
pH	8.78	8.5	7	0.117	0.326	1.19	0.038	119.2	4.57	393.3
Temp.	23.79	40	0	0.025		0.59	0.008	59.48	0.48	
Cond.	274	300	0	0.03		0.58	0.001	58.3	0.06	
Turbidity	264.99	5	0	0.2		52.99	0.065	5299.	345.72	
DO	7.03	5	14.6	0.2		0.78	0.065	78.8	5.143	
Nitrate (NO_3)	0.21	50	0	0.02		0.004	0.006	0.43	0.0281	
TP(mg/l	0.59	0.4	0	2.5		1.68	0.815	168.2	137.16	
FC	788.75	0	0					0	0	
TC	17195.24	0	0	3.1		57.84	1	578	4	

Trophic status indices of Lake Ziway

The present study indicated that the trophic status of Lake Ziway computed using average values falls under the hypereutrophic category (Table 7), based on the criteria developed for temperate waters (Carlson, 1977), and also models developed for tropical waters by Lamparelli (2004) and Cunha *et al.* (2013). However, some discrepancies were observed when individual sites were considered. For example, according to Carlson (1977) three sampling sites Center, Meki and Katar were grouped under the hypereutrophic condition while Bulbula, Gebrel, F.F, and Korekonch were under eutrophic condition. But the overall mean TSI values indicated hypereutrophic condition following the three models of Carlson (1977), Lamparelli (2004) and (Cunha *et al.*, 2013), which recorded mean TSI values of 82, 68.7 and 59.6, respectively. According to Dessie Tibebe (2017; 2020) and Hayal Desta *et al*, (2015), the main driving forces for ecological changes leading to the hypereutrophic state were reported as the increased population and anthropogenic activities in the Lake Ziway catchment. Regarding the differences between the temperate and tropical models. the Carlson model used for computing the trophic status included Secchi depth while Lamparelli (2004) and (Cunha *et al.*, 2013) did not consider Secchi depth but only Chl a and TP. This study therefore promotes the use of less costly methods to infer the ecological conditions of tropical lakes and reservoirs.

Table 7. The overall TSI values of Lake Ziway based on the three models.

TSI Model/index		TSI value estimated for L. Ziway	Trophic state classification
Carlson (1977)	TSI SD	65	Eutrophic
	TSI TP	97	Hypereutrophic
	TSI Chl a	86	Hypereutrophic
	Overall TSI	82	Hypereutrophic
TSI Lamparelli (2004)) modified from Carlson (1977)	TSI TP	71.3	Hypereutrophic
	TSI Chl a	64.1	Hypereutrophic
	Overall TSI	68.73	Hypereutrophic
TSI tsr (Cunha *et al.*,2013)	TSI TP	59.1	Super - hypereutrophic
	TSI Chl a	60.1	Hypereutrophic
	Overall TSI	59.6	Hypereutrophic

CONCLUSION AND RECOMMENDATION

The present study showed that nutrients such as phosphates and nitrates were much higher in the flower farm site and river mouth sites and could have triggered the changes that led to poor water quality and hypereutrophic status of Lake Ziway. Earlier studies have confirmed that nutrients and chemicals that are released from flower farm industries, agricultural lands, and municipal wastes were causes for the deterioration of water quality and expansion of water hyacinth in Lake Ziway (Ayenew and Legesse, 2007; Dessie Tibebe *et al.,* 2017, 2018; Hayal Desta, 2021). The high phosphate input into the lake (TP and SRP) account for the high algal biomass of all taxa and increased eutrophy of the lake. The TSI values computed from different models recommended for tropical waters (Lamparelli, 2004; Cunha *et al*., 2013) generally agreed in this case with the classical Carlson model developed for temperate waters (Carlson, 1977), even though the tropical models used fewer parameters. Therefore, this study promotes the use of Lamparelli and Cunha models to calculate the TS of tropical lakes and reservoirs and can arrive at safe conclusion regarding the ecological status of the water bodies with lesser data. This study clearly concluded that Lake Ziway has poor WQ index and is hypereutrophic and not eutrophic (Dessie Tibebe *et al.,* 2018) or in the trend of undergoing oligotrophication (Girum Tamire and Seyoum Mengistou, 2012) because these results were reported by including turbidity data This study clearly supports urgent ecological and administrative measures to reverse the ecological degradation of Lake Ziway. Furthermore, research should be done to corroborate the water quality and trophic status of Lake Ziway using biological indicators such as diatoms, macro-invertebrates, macrophytes, and other bio-assessment tools.

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