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Water Quality and Productivity Assessment of Lake Tinishu Abaya for Multiple Designated Water Uses, Ethiopia

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Abstract

Lake Tinishu Abaya, which is also known as Small Abya, is a shallow and small-sized inland water body in the rift valley lakes basin of Ethiopian. The lake is a source of livelihood and supports many socioeconomic activities of which fishing, small-scale irrigation, and domestic water uses are among others. However, the lake has not given attention predominantly due to its remote location and having a small size compared to other rift valley lakes of Ethiopia. The purpose of this research was, therefore, to determine the water quality and productivity of Lake Tinishu Abaya with respect to the changes in various physicochemical factors to give a long-term information for multidimensional use of the Lake water. Water samples collection was carried out for a year on a monthly basis between January and December 2016 from two predefined sampling stations (open and shore). In-situ and Laboratory measurements of the various physicochemical parameters (Temperature, pH, DO, conductivity, TDS, TSS, water transparency, euphotic depth, NH^4, NO_2, NO_3, SiO_2, SRP, TP) were performed using the standardized method. The trophic state was determined using Carlson's trophic state determination of an inland water body. The results of the study generalized that the lake water is well oxygenated, slightly warm, alkaline; and contained more TSS, TDS, and Electrical conductivity. The lake water was very turbid, low transparency, and fresh water. The major inorganic nutrients were relatively high. The study also revealed that the trophic nature of the lake was a eutrophic system which shows the lake water is productive. Most of the physicochemical parameters and major inorganic nutrients analyzed indicated that the water quality and productivity of the Lake Tinishu Abaya is suitable for the survival of most of aquatic life, fishing, irrigation and many other related multidimensional uses.

Keywords: Lake Tinishu abaya; Physicochemical; Rift valley lake; Trophic state; Water quality

Introduction

The quality of any water body is governed by its physicochemical factors and biological characteristics [1]. The distribution and productivity levels of organisms are largely determined by physicochemical factors [2]. Water quality parameters provide the basis for judging the suitability of water for its designated uses and to improve existing conditions [3]. For optimum development and management for the beneficial uses, current information is needed which is provided by water quality programmers [4], and in order to benefit from lakes, it has to know the characteristics of water. Ethiopia is endowed with a large number of standing water bodies, whose sustainable use can contribute to the economy of the country [5]. The lakes are critical to the survival of local communities as they are the actual and potential sources of food and income [6]. Despite their importance, the limnology of some of the Ethiopian lakes is unexplored. Lake Tinishu Abaya is one of such lake, which has not received attention in spite of its potential economic importance. Lake Tinishu Abaya is an important inland small-sized and shallow freshwater in the main rift valley lakes basin of Ethiopia. Based on the preliminary survey carried out by this researchers, the lake is a source of livelihood and supports many socioeconomic activities including fishing, small-scale irrigation, and domestic water uses among others. Despite the fact that Lake Tinishu Abaya/Small Abaya play a lot of roles for the local community, there is no any previous limnological studies were conducted. The lake is generally ignored and has not given attention maybe mainly due to its remote location and having a small size compared to the other nearby rift valley lakes of Ethiopia. The aim of this research was, therefore, to investigate the water quality and trophic status of Lake Tinishu to observe the potential of the lake water productivity.

Materials and Methods

Study area

Lake Tinshu Abaya, or Small Abaya, is a small freshwater lake located in the Rift Valley nearly 160 km southwest of Addis Ababa, Ethiopia (7°29´03.65´´N, 38°03`17.79´´E, 1835 m above sea level) (Figure 1). The lake, situated in a remote area 15 km from a small village (Gebribere Kebele) in the township of Silttie. It has a surface area of 1253 ha. [7], with a maximum and a mean depth of 3.7 m and 2.9 m, respectively (survey on this study). It is a shallow and small-sized Lake. Dacha and Bobodo rivers are the two feeder rivers for lake Tinishu abaya. During this study, two major perennial rivers (Rivers Dacha and Boboda) and a single outlet (River Badober) were always active. The former two rivers are relatively big. The lake has some commercially important fish species including the native *Tilapia Zilli* and *Barbus* species, while Nile tilapia (*Oreochromis niloticus)*, was stocked from the nearby Lake Ziway in 1997 [7].

Sampling protocol

For physicochemical and biological measurements, sample collection procedures were carried out on a monthly basis between January 2016 and December 2016 from two predefined sampling

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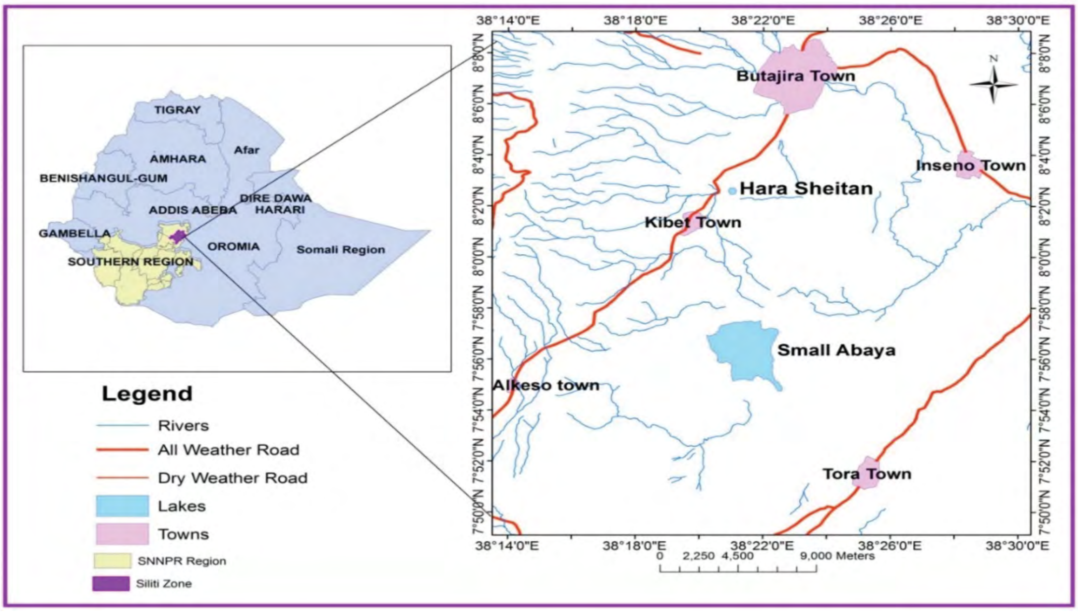

Figure 1: Location of Lake Tinishu Abaya/Small Abaya (Source: www.earth.google.com) and sampling sites (open site: 07° 56.658' N and 038° 21.787' E at elevation of 1822 m) and shore site: 07° 57.234' N and 038° 22.037'E at elevation of 1822 m).

stations, one from an area of high human impact (shore station: 07° 57.234' N and 038 22.037' E at elevation of 1822 m) and the second was from a relatively less human-impacted area (open station: 07° 56.658' N and 038° 21.787' E at elevation of 1822 m). The open-water site is located in the center; 2.5 km far from the shoreline of the lake. This was relatively protected from the direct human impacts. The wastes from their domestic animals such as cattle and related agricultural byproducts cannot easily enter and reach the open-water site especially in a dry season where no flood to carries the waste matter from the watershed; and hence the site is considered relatively protected from human impacts. On the other hand, the shore site is so close (nearly 50 m) to the edge of the lake. This site was considered as a direct recipient of wastes from agricultural land as well as domestic materials; thus the site was taking into consideration as impaired by human activities compared to the open-water site.

Measurement of physicochemical parameters

In-situ measurements for the parameters temperature, dissolved oxygen (percentage saturation), conductivity and pH was measured using a portable multimeter (Model HQ 40d Multi Hach Lange) and water transparency was measured using a standard Secchi disc having 30 cm in diameter. The euphotic depth (Zeu), the depth at which 1% of the surface photosynthetic active radiation is detected, for the study area, was calculated from the relation Zeu=4.6/Kd [8]. Turbidity was measured using portable digital turbidimeter (Model OAKTON: T-100). In the Laboratory, total suspended solids (TSS) were determined through the standardized gravimetric method for examination of TSS in water analysis by Howard. Total Dissolved Solids (TDS), the portion that passes through a filter, in a sample correlates to electrical conductivity [9] (TDS=0.65 × electrical conductivity). The major dissolved inorganic nutrients (SRP, TP, SiO_2, NO_2, NO_3, NH_4) were determined using the standard method of APHA (Table 1) at Limnology laboratory of Addis Ababa University (Ethiopia) [10]. Chlorophyll-*a* was determined spectrophotometrically [11].

Trophic state determination

The Trophic state of Lake Tinishu Abaya was determined using Carlson et al. [12] trophic status index (TSI) (equation-1 below), which was calculated based on Secchi disk transparency, Chlorophyll-*a* content, and concentration of total phosphorus.

Equation-1: Carlson et al. [12] trophic state equation

TSI Secchi Depth=60-14.41(In Secchi depth (meters))

TSI Secchi phosphorus=14.41 ln(TP)+4.15

TSI Chlorophyll a=(9.8)(ln Chlorophyll-a(μg/L)+30.6)

CTSI(Average)=(TSI-SD-TSI-TP+TSI-CHL-A)/3

Where: TSI=trophic state index, CTSI=Carlson's trophic state index, ln=natural logarithm. From this equation, Carlson's estimated the trophic state values ranged from Oligotrophic (TSI, <40), Mesotrophic (TSI, 40-50), Eutrophic (TSI, 50-70) and Hypereutrophic (TSI, >70) states (Table 2).

Statistical analysis

The Pearson correlation 'r" was performed to determine affinities among the physicochemical parameters. One way Analysis of variance (ANOVA) was used to analyze the significant difference of environmental parameters between spatiotemporal viabilities. Microsoft Excel and SPSS version 20 software also used.

Results

Temperature and dissolved oxygen

As expected from a small-sized and shallow lake, which induced the occurrence of complete mixing, most of the physicochemical parameters were more varied seasonally ($p<0.05$) than spatially. The value of surface temperature ranged from 18.5°C to 27°C at open water station and 18.5°C to 29.2°C at offshore station, while surface dissolved

Parameters	Site	Mean ± SD	Range	N
Temperature (°C)	OS	23.08 ± 3.0	18.5-27	12
	SS	23.23 ± 3.32	18.5-29.2	12
TSS (mg $CaCO_3$/L)	OS	148.32 ± 56.76	73-243	12
	SS	200.47 ± 89.19	76-368	12
DO (mg/L)	OS	9.04 ± 3.07	5.58-15.1	12
	SS	8.53 ± 1.77	6.1-11.62	12
Chl-*a* (µg/L)	OS	31.21 ± 13.77	18.97-65.05	12
	SS	26.30 ± 13.30	12.13-48.77	12
Total alkalinity (meq/L)	OS	4.56 ± 2.64	1.44-8.26	12
	SS	3.89 ± 1.99	0.96-6.94	12
Sechi Disk (cm)	OS	22.03 ± 4.42	16-28.5	12
	SS	14.22 ± 1.40	12-16.5	12
pH	OS	8.47 ± 0.39	8.11-9.27	12
	SS	8.53 ± 0.35	8.15-9.22	12
Conductivity (µS/cm)	OS	420.53 ± 352.34	181.1-1006	12
	SS	384.53 ± 315.03	147.7-1006	12
Turbidity (NTU)	OS	111.5 ± 31.32	57-143	12
	SS	135.42 ± 44.47	71-188	12

Table 1: Mean and range value of physicochemical parameters of Lake Tinishu Abaya at the open station (OS) and shore station (SS) during the study period (January-December, 2016).

Nutrients (µg/L)	Site	Mean ± SD	Range	N
NO_2	OS	503.82 ± 427.77	68.11-1314.18	12
	SS	626.32 ± 442.56	80.98-1447.6	12
NO_3	OS	192.14 ± 55.75	141.8-351.44	12
	SS	42.26 ± 11.57	152-341.02	12
NH_4	OS	47.44 ± 13.92	28.91-71	12
	SS	51.34 ± 20.27	33.33-95.85	12
SRP	OS	36.11 ± 8.63	24.1-48.13	12
	SS	42.26 ± 11.57	27.83-60.17	12
TP	OS	172.13 ± 95.3	56.73-285.5	12
	SS	184.41 ± 92.02	75.65-294.5	12
SiO_2	OS	62.80 ± 53.89	21-185.67	12
	SS	62.48 ± 50.96	20.99-180.89	12

N=Number of sampling month

Table 2: Mean and range value of major inorganic nutrients (µg/L) of Lake Tinishu Abaya at the open station (OS) and shore station (SS) during the study period (January-December, 2016).

oxygen (DO) ranged from 5.85 mg/L to 15.1 mg/L and 6.1 mg/L to 11.62 mg/L at open water and offshore stations, respectively (Table 1). The minimum and the maximum value of temperature observed in December and June, respectively at both shore stations (Figure 2). The high value of DO was observed from January to March (dry season) then showed an oscillation (Figure 2). Surface temperature and dissolved oxygen correlated strongly and negatively (r=-0.46).

In this study, the depth profile of temperature and dissolved oxygen were measured and it put in Figure 3. The water temperature at the deepest depth of measurement (2.5-3 m) at open station ranged from a minimum of 17.84°C at 2.5 m in September to a maximum of 22.5°C at 3 m in April. The temperature difference between surface and maximum depth (2.5-3 m) at the open station was 0.1°C in August and 6.4°C in February, the latter representing the largest temperature difference between surface and a maximum depth of the column of the lake water. Similarly, at shore station, the water temperature at the deepest depth of measurement (1.5-2 m) ranged from a minimum of 18.1°C at 1.5 m in December to a maximum of 25.1°C at 1.5 m in May. On the other hand, from the study of depth profiles of dissolved oxygen of Lake Tinishu Abaya, all depth profiles showed oxygen maximum in the upper layer of the water column and it declined with increasing depth. During the study period concentration of dissolved oxygen at the maximum depth (3 m) showed temporal variations from a minimum of 4.84 mg O_2/L in August to a maximum of 7.32 mg O_2/L in April at the open station. Oxygen-maxima were observed between 0-0.5 m depths in most of the sampling months. Oxygen-maximum was found at a shallow depth near the surface (at 0.5 m depth) in January, February, and April (Figure 3).

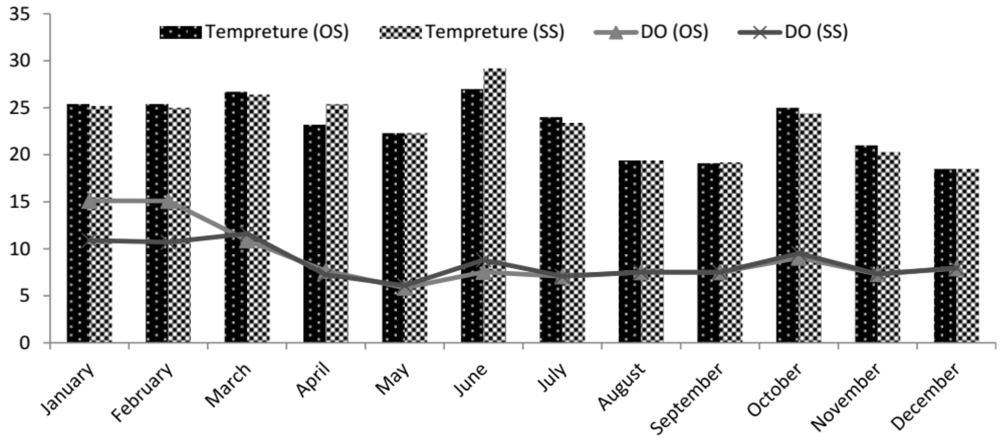

Figure 2: Spatiotemporal variations in surface temperature (°C) and dissolved oxygen (DO, mg/L) for Lake Tinishu Abaya at the open station (OS) and shore station (SS).

pH, alkalinity, electrical conductivity and Total Dissolved Solids (TDS)

The pH of the study lake ranged from a minimum of 8.11 to a maximum of 9.27 at the open water station and from 8.15 to 9.22 at an offshore station. Total alkalinity varied from a range of 1.44-8.26 meq/L and 0.96-6.94 meq/L at open water and offshore stations, respectively (Table 1). pH showed a seasonal variation with a significant difference (P=0.000). The high value of pH was seen during the dry season (January-May and October to December) (Figure 4). The total alkalinity of the study lake also showed marked temporal fluctuations (P=0.004). The high values of total alkalinity observed from January to April (dry period) and low from July to September (rainy period) (Figure 4). pH and alkalinity correlated significantly and positively (r=1).

The electrical conductivity of surface water for the study lake varied from 181.1 μS.cm^{-1} to 1006 μS.cm^{-1} at open water station and 147.7 μS.cm^{-1} to 1006 μS.cm^{-1} at offshore station. Electrical conductivity varied seasonally ($p<0.05$). The high value of conductivity recorded during the dry period (January to March) while the low value was observed during the main rainy season (June-September) (Figure 5). In this study, both sites have shown a fairly high amount of total dissolved solids (TDS). It was varied from lower values of 117.7 mg/L to a higher value of 653.9 mg/L at the open water station and 96 mg/L to 653.9 mg/L at the offshore station (Table 1). There was a seasonal effect ($p<0.05$) on the distribution of TDS. High TDS was observed in time of the dry period particularly from January to March and sharply decreased from April to September. Low values of TDS were reported in all the rain period (June to September) (Figure 5). it was perfectly and positively correlated with electrical conductivity (r=1).

Total Suspended Solids (TSS), turbidity, water transparency and euphotic depth

In the study lake, TSS was estimated and it was ranged from 73.24-243 mgCaCO$_3$/L and 76-368 mgCaCO$_3$/L at open water and offshore stations, respectively (Table 1). TSS varied seasonally with significant differences (P=0.000) in which high values were reported during the rainy season. The peak value was reported in July and August (rainy period). Low values of TSS were observed from November to January (Dry period) (Figure 6). The other most important parameters measured in the present study was water turbidity. Lake Tinishu Abaya was highly turbid throughout the year. Turbidity varied from 57 to 143 NTU at the open water station and 71 to 188 NTU at the offshore station (Table 1). It was varied seasonally with a significant difference (P=0.008) with high values were reported during the main rainy season (June and July). Comparatively, low turbidity was reported in the dry season, particularly from January to April (dry period) (Figure 7). During the study, water transparency (Secchi disk) of the lake was detected. Water transparency (Secchi disk) of Lake Tinishu Abaya varied from a low value of 16 cm to a high value of 28.5 cm at the open water station and from 12 cm to 16.5 cm at the offshore station (Table 1). A significant ($p<0.05$) seasonal variations of Secchi disk was observed for the study lake. High values of water transparency were recorded during the time of the rainy season (June-September) (Figure 7). The euphotic depth (Zeu), the depth at which 1% of the surface photosynthetic active radiation (PAR) is detected, for the study area, was calculated at the open water station, and it was ranged from a low value of 0.51 m to a high value of 0.91 m (Figure 8).

Inorganic nutrients

The major inorganic nutrients analyzed in the present study were nitrogen (nitrite-NO_2, nitrate-NO_3-N, ammonium-NH_4-N), phosphorus (soluble reactive phosphorus-SRP and total phosphorus-TP), and dissolved silicate (SiO_2). The annual mean concentration of NO_2, NO_3, NH_4, SRP, TP, and SiO_2 were, 503.82, 192.14, 47.44, 36.11, 172.13, and 62.80 μg/L at the open water station and 626.32, 42.26, 51.34, 42.26, 184.41, and 62.48 μg/L at the offshore station, respectively (Table 2). The spatiotemporal variations of inorganic nutrients are present in Figure 9. Nitrite and ammonium nutrients were varied seasonally ($p<0.05$) with higher concentrations reported during the main rainy season (June to September), and they were reduced in the dry season (November to February). Conversely, high values of nitrate were observed in the dry season and its peak value was seen in November. Phosphorus nutrients showed a significant seasonal variation ($p<0.05$). High SRP and TP concentrations recorded in a dry and rainy season, respectively. The peak value of SRP was seen from January to March (dry period) and its relatively lower value was observed from June to July (rainy period). A clear oscillation was observed in the concentrations of TP. It was maximum from May to July then reduced in August, then after it increased again from September to October. The lower value of TP was seen in January and

February (dry period). Reasonably, low dissolved silica was reported in the study lake throughout the study period.

Trophic state

The Trophic State of Lake Tinishu Abaya was determined using Carlson et al. [12] trophic state index over a period of one year. Trophic state index (TSI) in terms of the Secchi disk (TSI-SD), total phosphorus (TSI-TP) and chlorophyll-*a* (TSI-CHL*A)* was ranged from 78.3-86.4, 59.25-81.66 and 59.56-71.56 at the open station and 85.96-90.55, 66.49-86.12 and 55.06-67.91 at shore station, respectively. The annual mean values of TSI-SD, TSI-TP, and TSI-Ch-*a* were 82.04 ± 8.1, 72.34 ± 22.41 and 62.5 ± 15 at the open station and 88.17 ± 4.56, 77.56 ± 19.63 and 61.52 ± 14.91 at shore station, respectively. Carlson's trophic state index (CTSI-the mean of the three STI's) varied from 67.72-77.92 and 71.23-78.9 with a mean value of 72.31 ± 10.2 and 75. 75 ± 7.67 at open and shore station respectively (Tables 3 and 4).

Based on the Carlson et al. [12] trophic state classification (Table 2), the results of TSI values in the present investigations given strongly suggested that Lake Tinishu Abaya classified as a hypereutrophic state based on the mean values of TSI-SD and TSI-TP and eutrophic state based on the mean value of TSI-CHL*A* (Table 3). The overall trophic state of Lake Tinishu Abaya was a hypereutrophic system based on the average value of the three TSI's values (CTSI) (Table 3). The trophic state index in terms of chlorophyll-a was lower than the trophic state indices of Secchi disk and total phosphorus which indicated that the hypereutrophic state of Lake Tinishu Abaya is as a result of the presence of high concentration of phosphorus and low water transparency rather than algal bloom/algal turbidity.

TSI-TP was higher during the rainy time (June to September) and relatively low during the dry period (January to May and October to December). TSI-SD were above 70 throughout the study period which indicated in the hypereutrophic sate of the lake water year round. TSI-SD was high from May to July and low from August to September and from January to April (Figure 2). Generally, high TSI-SD was observed during the dry season with a peak in December at both stations. Except for December (TSI-CHLA=71.56), STI-CHLA was found between 50-70 throughout the study period indicated eutrophic state. TSI-CHLA progressively decreasing from January to August and then increased from September to December in 2016 (Figures 10 and 11). The peak CTSI value was observed in March, September, June, and July (Figure 10).

Discussion

Physicochemical features

In the study area, there is a relatively high temperature and dissolved oxygen, which indicated the lake is relatively warm and well oxygenated. In the study, a considerable temperature fluctuation was observed which could be influenced considerably by meteorological factors such as air temperature, humidity, wind speed, solar radiation and climatic factors. Dissolved oxygen showed temporal variation that might be the result of the variations observed in phytoplankton photosynthetic activity, thermal regime and/or changes in the weather conditions of the lake area. Bachmann et al. [13] considered that whereas wind is a major oxygenator in large lakes, dissolved oxygen in smaller lakes (a prominent feature of Lake Tinishu Abaya) is largely determined by photosynthetic action of planktons and complete oxygen depletion was not observed, apparently because of significant water movement through the lake as a result of mass water movement due to frequent top-down mixing. A similar fact was observed in Lake Tinishu Abay in which oxygen was not completely depleted throughout the study period owing to its water movement, in turn, the occurrence of complete mixing. Dissolved oxygen below 5 mg/l adversely affects aquatic life [14]. (>5 mg/L) standard for the survival of aquatic life. The concentration of DO level for the study lake indicated that it is suitable for the survival of aquatic life as per WHO prescribed.

In the study of depth profile of temperature, the decline in temperature per meter of depth by about 1°C or more than 1°C with increasing depth was observed near the surface in the 0-2 m depth layer in three months of the sampling period (January, February and March) and in all the remaining sampling months (April-December) temperature differences was less than 1°C down the column. In the 0-1 m depth layer, temperature gradients varied from 2.3°C in March to 3°C

TSI values	Trophic status	Attributes
<40	Oligotrophic	Clearwater, oxygen throughout the year in the hypolimnion, will anoxic during the summer
40-50	Mesotrophic	Water moderately clear but an increased probability of anoxic during the summer, decreased transparency, warm-water fisheries only
50-70	Eutrophic	Dominance of blue green algae, algal scum probable, extensive macrophyte problem
>70	Hypereutrophic	Heavy algal blooms possible throughout the summer, summer fish kills, few macrophytes

Table 3: Carlson's trophic state index values and classification of lakes (Carlson) and its attributes.

TSI parameters	Site	Mean ± SD	Range	N
TSI-SD	OS	82.04 ± 8.1	78.3-86.4	12
	SS	88.17 ± 4.56	85.96-90.55	12
TSI-TP	OS	72.34 ± 22.41	59.25-81.66	12
	SS	77.56 ± 19.63	66.49-86.12	12
TSI-CHLA	OS	62.5 ± 15	59.56-71.56	12
	SS	61.52 ± 14.91	55.06-67.91	12
CTSI	OS	72.31 ± 10.2	67.72-77.92	12
	SS	75. 75 ± 7.67	71.23-78.9	12

N-Number of studying months

Table 4: Trophic State Index (TSI) for Lake Tinishu Abaya in terms of Secchi disk (SD), total phosphorous (TP) and chlorophyll *a* (CHL*A*) and the average of each TSI's (CTSI-Carlson's trophic state index) (mean and range value).

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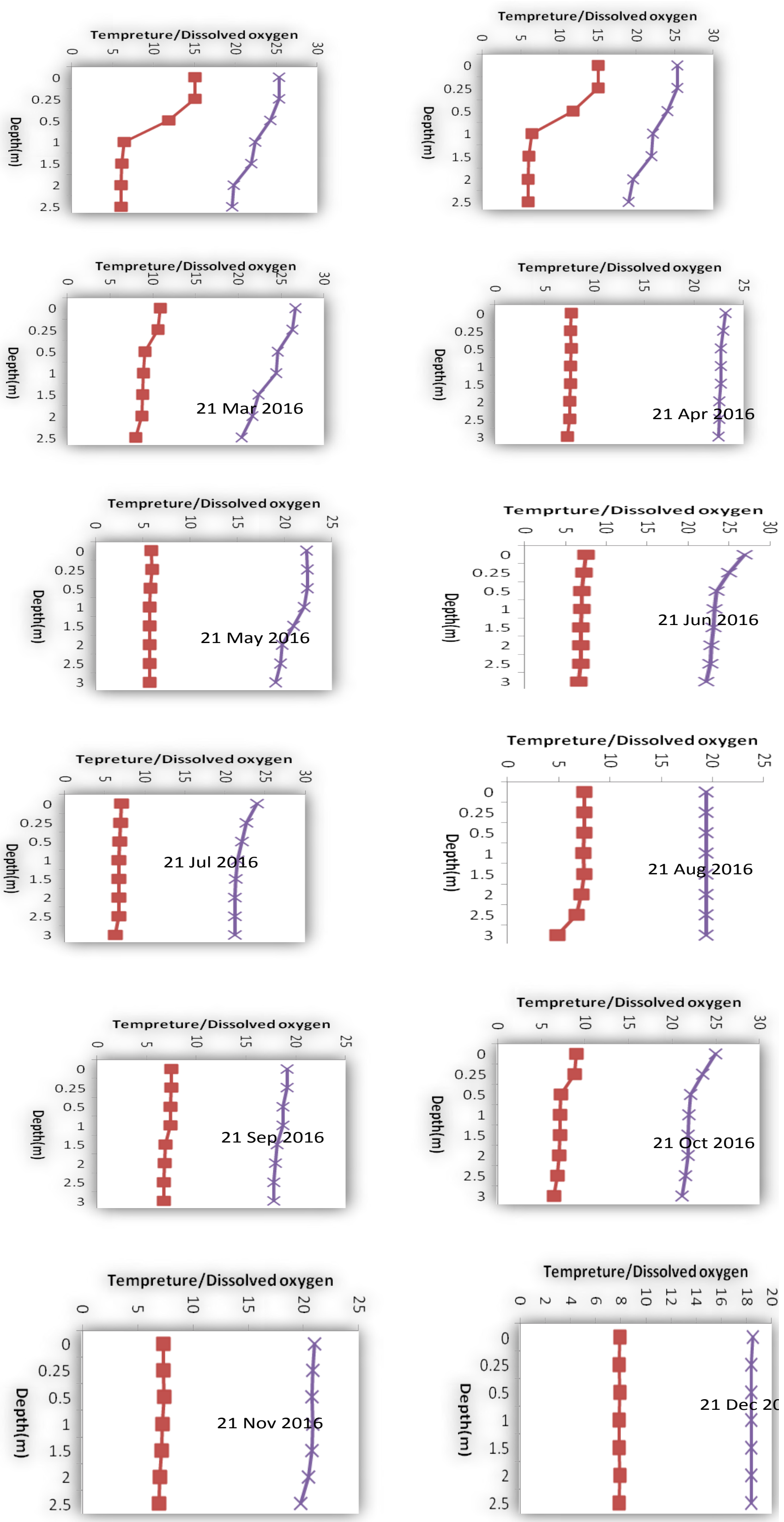

Figure 3: Depth profiles of Temperature (°C) (crosses) and dissolved oxygen (mg/L, boxes) in Lake Tinnishu Abaya at open station during the study period.

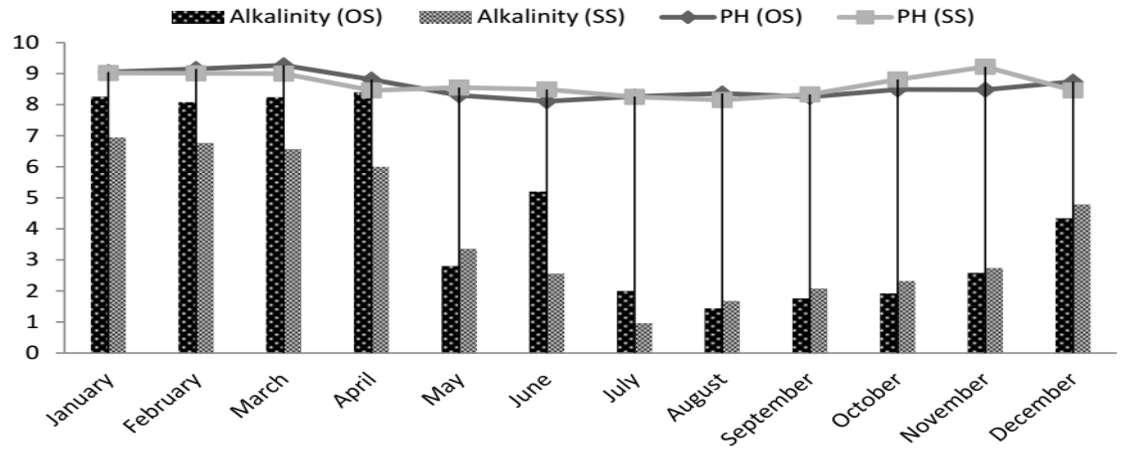

Figure 4: Spatiotemporal variations of pH and Total alkalinity (meq./L) for Lake Tinishu Abaya at the open station (SS) and shore station (SS).

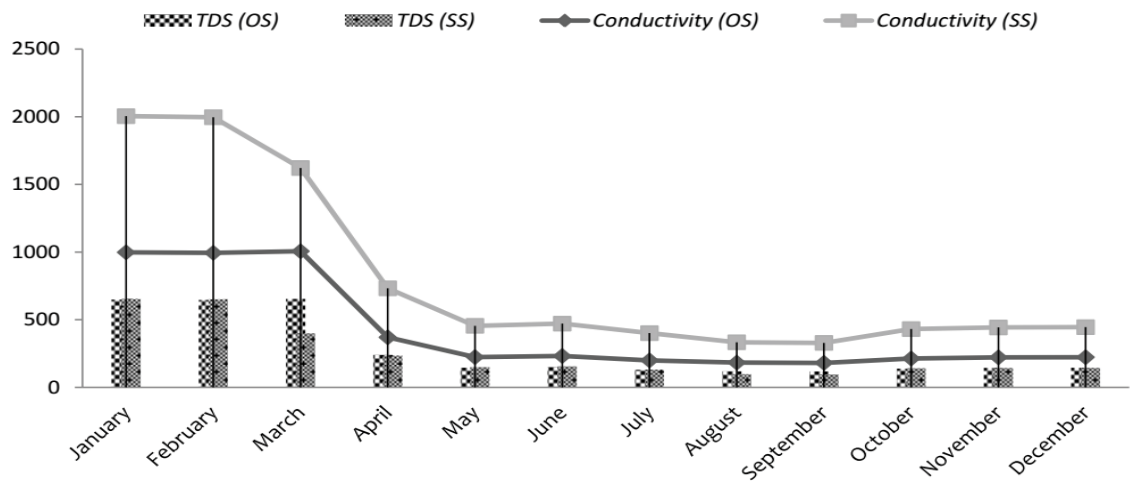

Figure 5: Spatiotemporal distributions of electrical conductivity (μS/cm) and total dissolved solids (TDS- mg/L) for Lake Tinishu Abaya at the open station (OS) and offshore station (SS).

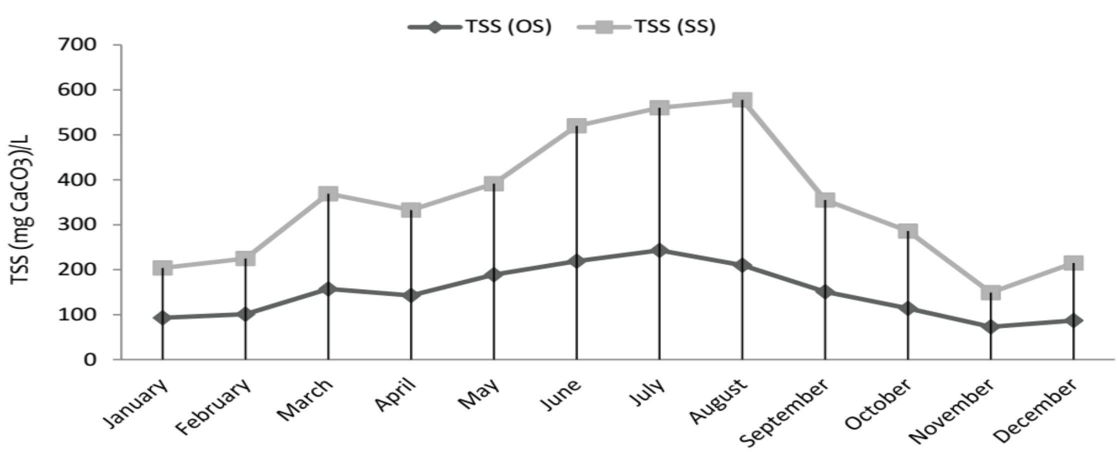

Figure 6: Spatiotemporal patterns of total suspended solids (TSS- mg $CaCO_3$/L) of lake tinishu abaya at the open station (OS) and shore station (SS).

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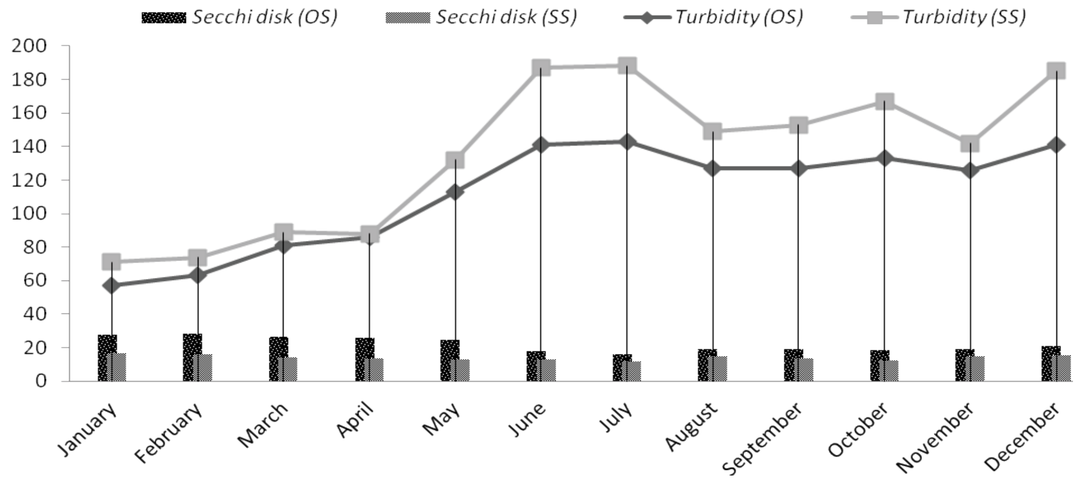


Figure 7: Spatiotemporal distributions of water transparency (Secchi disk) (cm) and turbidity (NTU) for Lake Tinishu Abaya at the open station (OS) and offshore station (SS).

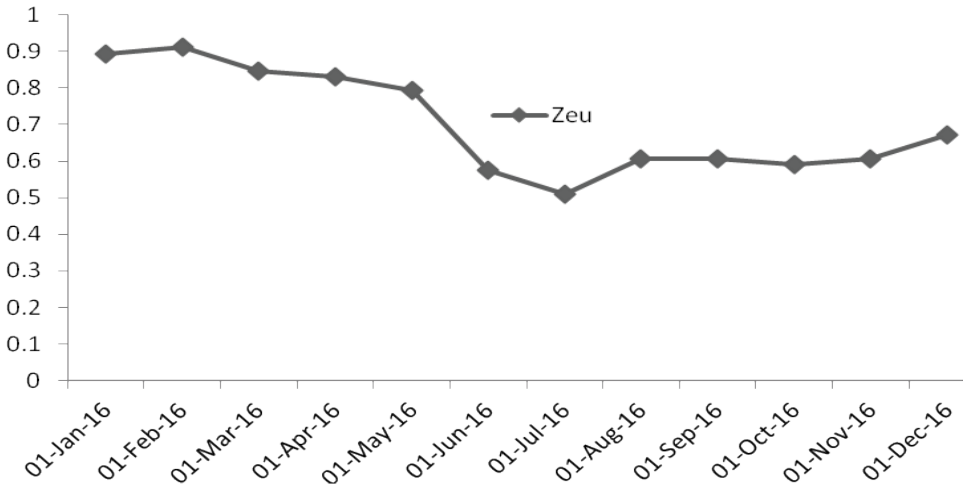
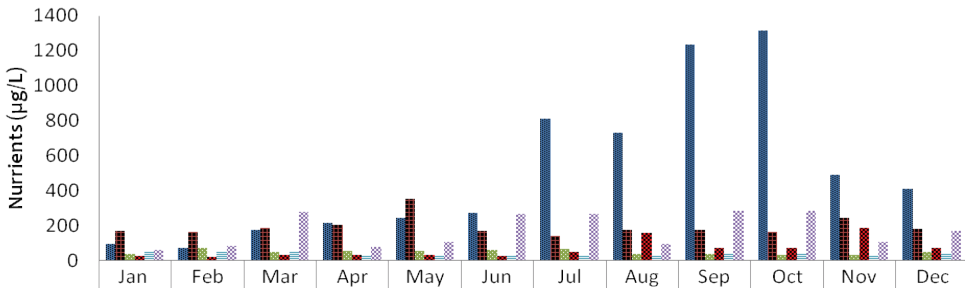


Figure 8: Temporal variations of Euphotic depth (Z_{eu}, m) for Lake Tinishu Abaya at the open station throughout the study time.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NO2	94.3	68.11	174.35	214.37	241.05	273.58	807.2	727.2	1234.1	1314.2	487.04	410.33
NO3	165.9	163	184.78	200.41	351.44	166.55	141.8	175.7	171.8	165.25	240.77	178.27
NH4	35.54	71	49.36	52.12	54.33	59.26	66.5	38.3	36.1	30.01	28.91	47.84
SiO2	22.27	21	28.27	30	32.77	25.49	45.3	154.8	68.5	68.83	185.67	70.74
SRP	48.13	45	48.13	29.73	31.1	25.77	24.1	32.7	37.8	42.97	28.35	39.53
TP	56.73	84	275.17	75.65	104.89	266.57	268.3	91.1	285.5	283.77	106.61	167.24

Figure 9: Temporal distributions of the major inorganic nutrients in Lake Tinishu Abaya.

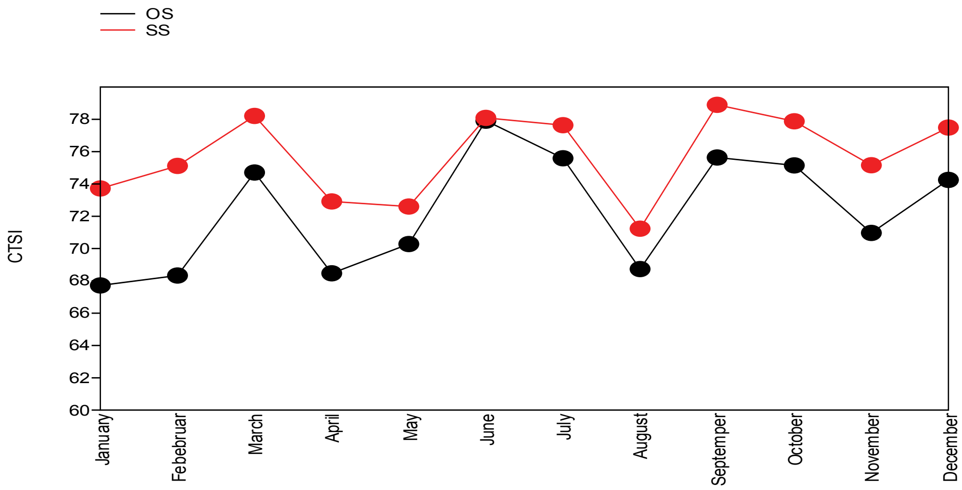


Figure 10: Carlson's Trophic State Index (CTSI) of Lake Tinishu Abaya (January-December, 2016).

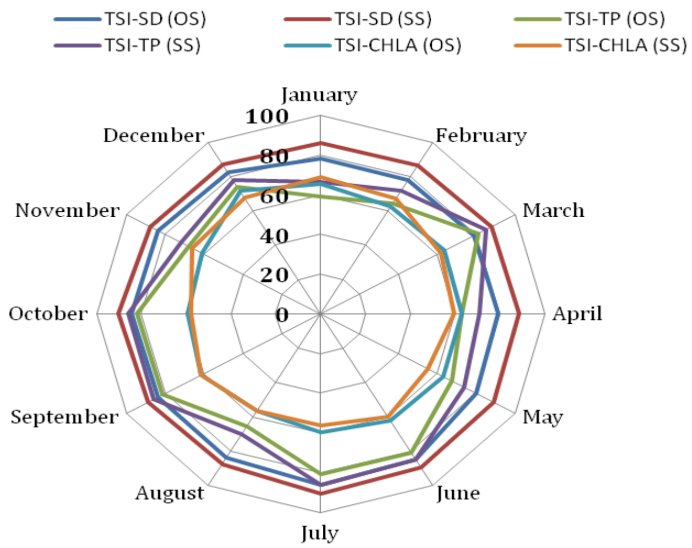


Figure 11: Radar diagram in the spatiotemporal variations of TSI values for each parameter (Secchi disk, TP, Chl-*a*) for Lake Tinishu Abaya at the open station (OS) and shore station (SS).

in January and in the 1-2 m depth layer, temperature gradients varied from 2.6°C in February to 2.9°C in January and there is no temperature stratification observed below 2 m in all sampling months. From depth profiles of temperature investigations, as expected from the shallow and small lake, persistent thermal stratification was not observed throughout the study period. The absence of this well-marked and persistent deep-seated thermal stratification owing to exposure to wind action which induces the persistence of complete mixing and difficult to see thermocline on depth profile in this very shallow lake. Thermal stratification with thermoclines extending between 2 and 7 m in Lake Hora Kilole was observed in 1990-1991 [15], which was associated with the increased depth attained after diversion of River Mojo and the cone-shaped water basin, which prevented wind-induced mixing. In Lake Tinishu Abaya similar thermal stratification was not observed even if the lake depth was increased during rainy season as a result of an increment of water availability via Rivers Bobodo and Dacha. From the study of depth profiles of dissolved oxygen of Lake Tinishu Abaya, all depth profiles showed oxygen maximum in the upper layer of the water column and it declined with increasing depth, which possibly due to the greater demand for oxygen for oxidative decomposition of organic matter by heterotrophs. Oxygen-maxima were observed between 0-0.5 m depths in most of the sampling months. Oxygen-maximum was found at a shallow depth near the surface (at 0.5 m depth) in January, February, and April. In these sampling months, the observed oxygen-maximum was may be associated with a superficial thermal stratification, which usually implies a steep temperature gradient in the uppermost 0-2 m stratum during warm and calm weather, and this gradient is a barrier to turbulent mixing resulting in *in-situ* accumulation of oxygen produced by photosynthesis. Depth maximum of oxygen can be formed when thermal gradient in the water column occurs within the photosynthetic zone [16].

From the study of oxygen depth profiles of Ethiopian creator lake, L Bishoftu [17] and Kuriftu [18] lakes, and the Ethiopian rift valley lakes Chamo, Hawassa et al. [19] and other Ethiopian lakes, Baxter et al. [16] indicated that most of the lakes showed an oxygen maximum in the uppermost 0-5 m layer, and in Lake Tinishu Abaya a similar feature was observed. The decline in oxygen concentration near the water surface in some tropical lakes is accentuated by the influence of rising temperature on the saturation concentration [16] and photo-inhibition [20,21]. Beadle et al. [22] argued that the major determinant of circulation in tropical lakes is wind rather than the seasonal fluctuations of illumination and atmospheric temperature. Pearson correlation analysis of the resent study indicated that temperature and DO correlated strongly and negatively (r=-0.449). On rainy season (August) of sampling day where increasing water level of the study lake, the value of DO were low in the part of the water column, a situation was observed in Lake Hora Kilole after attaining higher depth due to the diversion of River Mojo into it [15].

In the present investigation, the pH value showed that the water of Lake Tinishu Abaya was alkaline in nature throughout the study period. The alkalinity results suggest that the lake is highly productive. BSI [23] recommendation of pH is 6.5-8.5 for optimal survival of most aquatic life. A lower value of pH below 4 will produce sour taste. The minimum values of pH of the study lake are within the maximum permissible limits of [24] for recreation, agricultural, fish production and other aquatic life water use (6.5-8.5/9). As recorded in this study, Lake Tinisu Abaya is very turbid. This higher turbidity could be the result of rainfall which brought sediment-laden waters from the surface runoff via rivers Bobodo and Dacha, and because of surface run-off water with soil, domestic waste, cattle washing, bathing activity, and etc. The lake had relatively high TDS throughout the study. Water with total ionic concentration <3000 mg/L) is considered fresh. The acceptable range for livestock drinking is 100-1500 mg/l. Thus, Lake Tinishu Abaya is reasonably fresh based on the results of TDS, and it is recommendable for livestock drinking including fish production.

Lake Tinishu Abaya had low water transparency throughout the study period and, therefore, the lake is generally regarded as a productive lake. The significant lower water transparency is most likely due to wind-induced re-suspension of bottom sediments and this operates the large turbulence and sediment instability which in turn reduces the depth of light penetration. During the period of sampling, a lot of human activities including swimming, washing clothes, watering animals and damping of wastes were observed, and these activities may persuade and cause re-suspension of particles, have probably contributed to the lower water clarity of the study lake. Low water transparency during the rainy season may be because of high flushing rate, inorganic silt turbidity, and high loading of dissolved inorganic matter from the inflowing rivers, which is likely any other tropical lake [25].

Inorganic nutrients

Most of the inorganic nutrients measured in the study lake were relatively higher and supports most of the aquatic life. Majority of the nutrients were relatively high during the rainy season. This is because of the possible influx of nitrogen-rich flood water into the lake water from the amount of contaminated sewage water. The seasonal changes in NO_3+NO_2 concentration in Lake Tinishu Abaya seem to be controlled by the introduction of nutrients from external sources through runoff. Ammonium concentrations are lower than nitrate-nitrogen concentrations in most productive lakes after periods of circulation [26]. The same results were observed in the study lake. In Lake Tinishu Abaya, the concentration of dissolved silica is very low. Generally, over the last two decades, the Ethiopian Rift Valley lakes showed a decline in silicate concentrations [27,28]. The depletion of silica can be related to its removal from solution in diatom-dominated lakes [29] or its slower rate of regeneration resulting from the accumulation of organic matter as was shown for alkaline lakes in Africa [30]. Regeneration of phosphorus by zooplankton can be high enough to raise the ambient concentration to a level capable of supporting algal growth [31], which is not well studied in African lakes [32]. The fairly high level of TP in this lake is probably a result of zooplankton excretion. The release of phosphate from anaerobic sediments [33] and its subsequent transport to the epilimnion during mixing contributes to the high level of phosphate in the epilimnion, may result in the fairly high phosphate in the study lake. According to Ayers et al. [34], the required maximum concentration of NO_3 for livestock and irrigation were 100 and 30 mg/L respectively and the concentration below 5 mg/l will not affect flora. The concentration of nitrate in Lake Tinishu Abaya was within the permissible limits for flora, livestock, and irrigation. The maximum allowable concentration of phosphate for irrigation water is 2 mg/l [34]. The phosphorus concentration not greater than 300 µg/L shown the lake was not disturbed by anthropogenic factors [35]. Based on this fact the phosphate range in the Lake Tinishu Abaya water was within the permissible limit for irrigation and other purposes.

Trophic state

The trophic state of Lake Tinishu Abaya was determined based on Carlson et al. [12] trophic state index. TSI values given strongly suggested that Tinishu Abaya was classified as in a hypereutrophic state based on the average values of TSI-SD and TSI-TP and it was eutrophic based TSI-Ch-*a*. Based on the average value of the three TSI which is termed as Carlson's trophic state index (CTSI), the overall trophic state of Lake Tinishu Abaya categorized under the hypereutrophic system. The STI in terms of total phosphorus and chlorophyll *a* of Lake Tinishu Abaya (Table 2) was higher than the Ethiopian highland lake, L. Hayq which was categorized as eutrophic (TSI-CHL *a*=55.7) and TSI-TP=63) [36]. On average, the trophic state index of the Lake Hawassa was hypereutrophic (TSI=72.6), as Carlson value category [37]. The results of the average value of TSI for Lake Tinishu Abaya in the present study was fairly comparable with the nearby rift valley Lake Hawassa, Ethiopia. Shallow lakes, in general, do not exceed three meters in depth and are not stratified because of the mixing effect of the wind and such water-bodies usually have a high trophic state [38,39]. The same propensity was observed in Lake Tinishu Abaya in the present study.

In the study area, the trophic state index in terms of chlorophyll-*a* (TSI-Chl-*a*) was lower than the trophic state indices of Secchi disk (TSI-SD) and total phosphorus (TSI-TP) which indicated that the hypereutrophic state of Lake Tinishu Abaya is as a result of the presence of high concentration of phosphorus and turbidity/low water transparency rather than algal boom/algal turbidity. Even though blue-green algae dominated throughout the study, the problem of eutrophication as a result of algal growth was not observed for the study lake. The slightly higher TSI-TP at the shore station was probably associated with the greater exposure of the station to wind blowing and sediment run from the watershed which is very close to shore station results increasing concentrations of TP in turn increase TSI value. Generally, high level of value of TP at both stations owing to due to the possible influx of phosphorous nutrient rich flood water into the lake water from the catchment and contaminated sewage through runoff via rivers, in turn, increasing TSI-TP. Lake Tinishu Abaya had relatively low water transparency throughout the study period in both sampling sites makes it the lake to have to high TSI-SD value.

The lowest phytoplankton biomass measured was observed during the rainy season in June, July, August, and September at both stations and this result the relatively low value of STI-CHL*A* in the rainy time. This seasonal minimum Chl-*a* in rainy seasons coincided with a period of heavy precipitation that resulted in land runoff which brought particulate materials into the lake with a consequent reduction in light penetration owing to the lower value of chlorophyll production in turn low TSI-CHLA.

High CTSI values in rainy time owing to the concentrations of phosphorous nutrients from the catchments through runoff, increasing the water turbidity/decreasing water transparency of the lake. The main parameters for the increasing of TSI values in the study lake were water transparency and concentrations of phosphorus. Any change in phosphorus concentration of freshwater ecosystem can also alter its trophic status. According to Carvalho et al. [40] decline in the inflow of nutrients reduces phosphorus concentration in lakes which in turn reduces phytoplankton biomass. Kleeberg et al. [41] have advocated the direct role of phosphorus in eutrophication of water bodies but Bennion et al. [13] are of the opinion that phosphorus plays no direct role in eutrophication. Bergmen et al. [42] observed pronounced decrease in Secchi's depth transparency with the increase in phosphorus and chlorophyll-*a* concentrations. Xie et al. [43] reported persistent coincidence between the occurrence of microcystins bloom and that of phosphorus. In this study, the correlation between phosphorous and chlorophyll *a* was positive but weak (Table 2).

According to Steffanson et al. [44] although eutrophication is a natural process, over a period of time it is often accelerated by human activities. Human beings influence lake ecosystems increasing the concentration of plant nutrients, primarily phosphorus [45]. The nutrients may enter into lakes as agricultural runoff, sewage or wastewater and also by cattle ranching. This causes over-enrichment of nutrients in the water bodies leading to the algal blooms. The decaying process of dead algal biomass may also result in the depletion of dissolved oxygen in the lakes causing anoxic environment.

Conclusion

The various environmental parameters analysed in the present study to determine the water quality and productivity of the Lake Tinishu Abaya, showed that the lake water is less saline, fresh in nature, slightly warm, well oxygenated, very turbid, high electrical conductivity, and relatively with nutrient enrichment that supports and suitable for the survival of most of the aquatic lives, fish production, and irrigation. The overall determination of the trophic state of the lake is a hypereutrophic state, clearly indicated that signal of eutrophication for Lake Tinishu. The main parameters for the increasing of TSI values in the study lake were water turbidity and concentrations of phosphorous, other than chlorophyll a, which told the hypertrophic state of the lake is the result of high concentration of total phosphorus and water turbidity rather than algal turbidity. However, the concentration of high inorganic nutrients clearly indicated that signal of eutrophication for the lake. Even if anoxic condition as a result of eutrophication due to algal bloom was not observed in the present lake, the probability of its occurrence is high since there are high anthropogenic influences found in a very near shore site of the lake which results in the high concentration of nutrients including phosphorus. The continuous monitoring of the lake water is required to protect water in future from any possible contamination due to growing agricultural practice (/both large and small-scale irrigation) in the water shade of the lake. Thus management solution should be developed in order to avoid the destruction of the lake.

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