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The trophic condition of Lake Tana, Ethiopia

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ABSTRACT

The trophic condition of Lake Tana was conducted from 2017 to 2018. Eleven sites were chosen in total, nine on the shores and mouths of important rivers and the other two on the open water of Lake Tana during both the dry and wet seasons. Water transparency was measured using a Secchi disk and the total phosphorus was measured by the molybdate reactive phosphate method. A UV spectrophotometer was used to measure the absorbance of extracted pigment at wavelengths of 665 and 750 nm. Talling and Driver's (1963) formula was used to calculate chlorophyll a (Chl-a). The mean values for total phosphorus (mg L-1), Secchi depth (cm), and chlorophyll-a (Chl-a) were 0.48, 51.5, and 9.92 µg L^{-1}*, respectively. The trophic state of Lake Tana was estimated, and the trophic state index value of total phosphorus (*TSI_{TP}*) was 93.38 which implies that the lake was hypereutrophic. Trophic state index values of Secchi depth (*TSI_{SD}*) and Chl-a (*$TSI_{chl\text{-}a}$*) were 50.42 and 53.1, respectively implying that the lake is strongly mesotrophic. The Carlson Trophic State Index (*TSI_C*) was estimated by the average of trophic state index values of Secchi depth (*TSI_{SD}*), total phosphorus (*TSI_{TP}*) and Chl-a (*$TSI_{chl\text{-}a}$*). Thus, according to these three trophic state parameters (*TSI_C*) Lake Tana was a hypereutrophic lake. This may indicate the existence of high nutrient load entering into the lake from the catchment. As a result, concerned bodies must safeguard and reduce nutrient loads before they have a negative impact on aquatic ecology.*

1. INTRODUCTION

Lakes are commonly classified according to their trophic state, a term that describes how 'green' the lake and measured by the amount of algae biomass in the water (Carlson 1977). Three trophic state categories are used to describe lakes as they grow progressively greener: oligotrophic, mesotrophic, and eutrophic (Carlson 1977). Watershed managers typically do not determine trophic state by directly measuring algae biomass and hence the index number can be calculated from any of several parameters, including Secchi disk transparency, chlorophyll and total phosphorus (Carlson 1977 and Kalff 2002). Carlson (1977) developed a trophic state classification based on a combination of biological (chlorophyll-a), physical (Secchi disk, transparency), and chemical parameters (total phosphorus). Because phosphorus concentration inhibits algal growth in most lakes, it was chosen as one of the factors. The trophic index of Carlson (1977) has several advantages over previous attempts at trophic classification as they determine how much nutrient abatement is necessary to reach a desired trophic condition. The community structure and primary production of phytoplankton are available for many east African Lakes (Talling and Lemoalle 1998). Phytoplankton primary production is the corner stone of the entire aquatic ecosystem. Up to 70% of atmospheric oxygen comes as a result of the photosynthetic activity of aquatic micro and macro-algae (Reynolds 1994).

The amount of primary productivity in a lake is a better indicator of fisheries yield and total biomass (Ryder et al 1974; Downing et al 1990) and the trophic state (Carlson 1977). The amount of primary production and biomass is, in turn, dependent on several physico-chemicals and biological factors. Physical features such as mixing, stratification driven by wind regime and atmospheric temperature, determine the availability of nutrients to the phytoplankton in space and time (Levinton 2013). The degree of water transparency or turbidity determines the depth of light penetration, which, in turn, affects rate of photosynthesis (Dejen et al 2017 and Li et al 2019). The mixing pattern of the water body also determines the distribution of phytoplankton species in the water column. Planktonic species composition, density, age, and physiological states are among biological factors that determine the amount of primary production (Schindler et al 1977; Vollenweider 1991). Primary productivity also contributes to the amount of dissolved oxygen in water which is available for community respiration including fish (Lee et al 1996). However, increased biological oxygen demand can lead to oxygen depletion during complete mixing or massive nutrient enrichment, which results in increased oxidation of some compounds by bacteria (Carlson 1977; Vollenweider 1991; Carlson and Simpson 1996). Nutrient dynamics of a particular water body, thus, indirectly determines parameters like dissolved oxygen, pH, alkalinity and conductivity which, in turn, affect the physiological state of aquatic animals from zooplankton to fish (Lee et al 1991; Mays 1996; Wetzel 2001; Kalff 2002). Ethiopia is a land-locked country but endowed with relatively vast freshwater resources in the region (FAO 2016). The country is connected with twelve main river basins (FAO 2016). The Great East African Rift valley that bisects the country is home for diverse lakes, along with dozens of highland and crater lakes. According to Greboval et al (1994), the total area of inland waters in Ethiopia is estimated to be 8,800 square kilometers, representing 0.72% of the total surface area of the country (Greboval et al 1994).

Studies show that water bodies in Ethiopia are biologically productive in terms of phytoplankton, zooplankton, benthic and fish species that make up the aquatic food chain and food webs (Tudorancea et al 2002). The diverse aquatic ecosystems found in the country are of greater economic importance and provide ample opportunities for scientific studies (Zinabu 1994). Among the important lake ecosystems in Ethiopia are the Rift Valley Lakes and the associated Crater Lake systems and the highland lakes. The first series of limnological studies began in the 1960's focusing on the morphometric and limnological studies (Mohr 1961; Baxter et al 1965; Prosser et al 1968). The second series of studies later continued as several authors investigated some alkanity-salinity and planktonic studies (Talling et al 1973; Wood et al 1976). Wood and Talling (1988) have compiled some sporadic studies on the diversity of phytoplankton species in Ethiopian water bodies. Studies on the zooplankton diversity of these lakes date back to expeditionary studies in the 1930s. However, by the time the third series of limnological studies began in the 1990's, several water bodies in Ethiopia have undergone rapid changes in terms of planktonic content, trophic state, and chemical compositions (Brook 1994; Zinabu 1994; Elizabeth and Amha 1994; Elizabeth and Wiellén 1998). Zinabu (1994), related the changes to deleterious anthropogenic activities in the form of industrial pollution, changes in land cover in the upper water shades, such as improper agricultural practices and deforestation. In the late 1990s, some authors already found the extreme changes in the limnology and morphometric of some water bodies (Zinabu 2002) in which some lakes became nonexistent as a result of deleterious human intervention. In general, trophic state measurements serve as indicators of a lake management program's performance. As a result, determining the trophic condition is critical to intervene against anthropogenic consequences and maintaining biodiversity in aquatic environments. Considering the above points into account the objective of this study is to assess the trophic state of Lake Tana

2. MATERIALS AND METHODS

2.1. Description of study area

Lake Tana is the largest lake in Ethiopia, with an area of 3150 km^2, located at an altitude of 1786 m (Vijverberg et al 2009). Lake Tana is a crater lake formed two million years ago, due to the volcanic blocking of the Blue Nile River (Vijverberg et al 2009. It has a mean depth of 8 m and a maximum depth 14 m (Vijverberg et al 2009). The catchment area of Lake Tana is about 16,000 km^2. Lake Tana is fed by seven large permanent and 40 small seasonal rivers but four permanent rivers, namely Gilgel Abbay, Megech, Gumara, and Rib Rivers, which account for 95% of the inflow of the lake, while the Blue Nile (Abay) is the only outflowing river (Vijverberg et al 2009). Lake Tana is a highly turbid lake with low biological productivity, but unique diversity of cyprinid fish (Vijverberg et al 2009). Environmental changes in Lake Tana and its watershed, including eutrophication, associated with various anthropogenic activities that resulted in the destruction of wetlands, have been observed (Tewodros et al 2014). Recently, extensive stands of water hyacinth have been reported on the shore areas of this sensitive lake, one of the most ecologically dangerous weed infestations. Other weeds introduced to Lake Tana include the aquatic fern Azolla species (Wassie et al 2014). The shore of Lake Tana was covered with swamps whose macrophyte vegetation was dominated by papyrus (*Cyperus papyrus*), hippo grass (*Echinochloa stagnina*), elephant grass *(Phragmites karka*), introduced aquatic ferns (*Azolla* sp.), *Typha latifolia*, water lilies (*Nymphaea* sp.) and *Ceratophylum* sp. (Wassie et al 2014) The Southern part of Lake is mainly covered by *Ceratophylum* sp. *(*Ayalew 2006; Wassie et al 2014).

Sampling protocol

The selection site was based on the basis of the proximity of agricultural practices, the presence of industrial, domestic and urban influents, and rivers permanently feed the lake. Therefore, nine sites were selected on the shore and mouth of the main rivers, while two sites were selected on the open water of Lake Tana purposely (Figure 1). As a result, eleven typical sampling sites were used to collect samples and test physicochemical parameters in situ. The samples were collected in September, January, and August 2017 to 2018 on Lake Tana. Coordination point and local names of representative sites of Lake Tana were presented in Table 1.

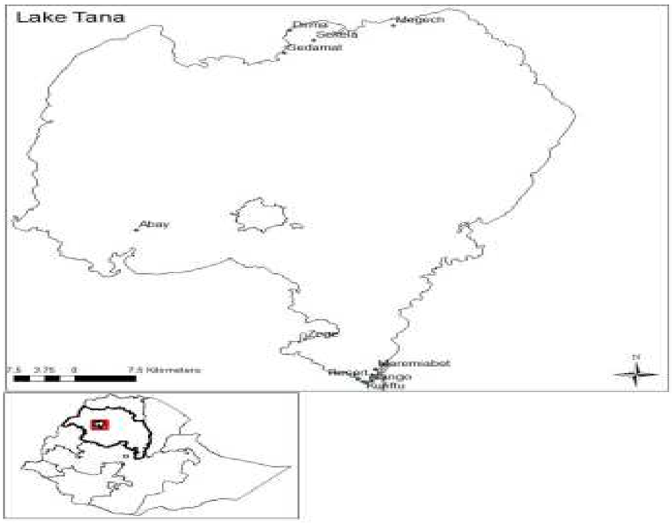

Figure 1. Representative sampling site map at Lake Tana.

Table 1: Coordination point and local name of sampling sites at Lake Tana

Codes of sites	Local name	Northing/Latitude	Easting/Longitude
S1	Blue Nile Resort	11°33'14.0"	037°18' 40.3"
S2	Mango	11°38'49.07"	037°23'21.567"
S3	Tana Hotel	11°30'23.34"	037°20'18.25"
S4	Zegie open water	11°40'32.5"	037°23'08.8"
S5	Abay River mouth	11°52'07.9"	037°07'59.2"
S6	Maremiabet	11°36'24.3"	037°24'03.5"
S7	Sekela open water	12 °13'31.2"	037 °18' 50.9"
S8	Megech River mouth	12°14' 44.2"	037°13'5.30"
S9	Derma River mouth	12°15'40.3"	037 °18'83.3"
S10	Gedamat	12 °12'50.2"	037 °17'33.3"
S11	Kuriftu Resort	11°35'55.1"	037°23'06.4"

Measurements of Water Transparency and total phosphorous

Water transparency was measured using a Secchi disk of 20 cm diameter. Total phosphorus was measured as molybdate reactive phosphate (MRP) after organically bound phosphorous was converted to orthophosphate by oxidative hydrolysis with potassium persulfate (APHA 1999). This means 50 ml sample water was added to the Erlenmeyer flask. Phenolphthalein was added on it. Then, 5N H_2SO_4 and potassium persulfate (K_2SO_8) were added to the solution, respectively. Thun, the solution was slowly heated until it reached a final volume of 10 ml. The boiling solution was chilled before adding phenolphthalein and 5N NaOH. Then, a combined reagent of potassium antimonyl tatrate solution, ammonium molybdate solution and ascorbic acid solution was added on sample solution. Finally, the absorbance of the solution was measured with Jenway 6300UV-VIS spectrophotometer at wavelength of 880 nm (APHA 1999).

Chlorophyll-a Biomass of phytoplankton

A 500 ml water sample was filtered using glass fiber filter papers (GF/F) and frozen immediately. Chlorophyll a (Chl a) was extracted in acetone and the pigment extract was centrifuged at 3000 rpm for 10 minutes (Talling and Driver, 1963). The absorbance of the extracted was measured with Jenway 6300 UV spectrophotometer at a wavelength of 665 and 750 nm (Wetzel and Likens 2000). The calculation of Chl-a concentration was done using the following formula (Talling and Driver 1963).

$$\text{Chl} - \text{a}(\mu\text{g}/\text{L}) = \frac{13.9(E665 - E750)Ve}{VfXZ}$$

Where, E665 and E750 are absorbance at 665 nm and 750 nm, respectively.

Ve = Volume of extract acetone in ml

Vf = Volume of sample filtered in liter

Z = Path length of cuvette (cm)

Trophic State of Lake Tana

The trophic state index of Lake Tana was estimated according to Carlson (1977). The Trophic State Index (TSI) of Carlson (1977) is a trophic state classification method that is based on total in-lake phosphorus concentration, in-lake Chlorophyll-a (Chl-a) and water transparency (Z_{SD}).

Secchi Disk Depth TSI (TSI_{SD})

$TSI_{SD} = 60 - 14.41*\ln Z_{SD}$ (m): where, "ln" is the natural logarithm

Chlorophyll-a TSI (TSI_{Chl})

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

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

$TSI_{TP} = 4.15 + 14.42*\ln TP$ (μgL^{-1})

The Carlson Trophic State Index (TSI_C) was estimated by the average of trophic state index values of Secchi depth (TSI_{SD}), total phosphorus (TSI_{TP}) and Chl-a (TSI_{chl-a}). Thus,

$$TSI_C = \frac{TSI_{TP} + TSI_{SD} + TSI_{Chl}}{3}$$

According to Carlson (1977) and Carlson and Simpson (1996) the model trophic states of the lake are classified in Table 2.

Table 2: Trophic state categories proposed for waters.

Trophic state		**Carlson and Simpson (1996)**
Eutrophic	Hypereutrophic	> 65
	Strongly eutrophic	62 - 64.9
	Eutrophic	58 - 61.9
	Slightly eutrophic	54 - 57.9
Mesotrophic	Strongly mesotrophic	49 - 53.9
	Mesotrophic	43 - 48.9
	Slightly mesotrophic	38 - 42.9
Oligotrophic	Slightly oligotrophic	33 - 37.9
	Oligotrophic	26 - 32.9
	Strongly oligotrophic	20 - 25.9

Statistical analysis

The mean variations of Secchi depth, total phosphorus and chlorophyll-a were analyzed between dry and rainy seasons with one-way ANOVA (SPSS Version 22).

3. RESULTS AND DISCUSSION

3.1. Secchi depth, total phosphorus and chlorophyll-a

Relatively high mean value of total phosphorus was recorded at site S11 during the dry season and at S5 a relatively high mean value of total phosphorus was recorded during the rainy season (Table 3); however, there is no significant difference ($P > 0.05$) between the two seasons in the mean value of total phosphorus (Table 4). At Lake Tana, the total mean total phosphorus was 0.48 mgL^{-1} during the dry and wet seasons (Table 3). Algal blooms in surface waters may occur if total phosphorus exceeds 0.15 mgL^{-1} (James 1997). The present mean of total phosphorus was relatively higher than the previous reported concentration of soluble reactive phosphorus for open water of Lake Tana < 0.1 mg L^{-1}, (Ayalew et al 2007). This relatively high concentration of total phosphorus could be due to the presence of agricultural practices around the lake Tana as it has been reported by Tewodros *et al*. (2014). Extreme input of nutrients into water ecosystems leads to excessive algal growth and causes eutrophication (Kalff 2002; Zinabu 1994). Therefore, it needs to reduce input nutrients, especially phosphorus (< 0.05 mgL^{-1}), (Adopt a wetland program, Delaware Department of Natural Resources and Enviromental control 2003) to control eutrophication of fresh water, including lakes (Zinabu, 1994 and Kalff 2002).

Table 3: Total phosphorus (TP, mgL^{-1}), Secchi depth (Z_{SD}, cm) and chlorophyll-a (Chl-a, μgL^{-1}) concentration of the sampling sites during the dry and rainy seasons in Lake Tana.

Sites	Season					
	Dry	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**
	TP (mgL^{-1})		Secchi depth (Z_{SD}, cm)		Chl-a (μgL^{-1})	
S1	0.16	0.68	80	86	8.27	7.30
S2	0.62	0.26	55	45	16.09	13.64
S3	0.52	0.89	51	30	11.99	9.47
S4	0.02	0.23	66	52	6.99	7.68
S5	0.18	1.65	20	23	12.99	2.08
S6	0.26	0.17	70	60	7.09	9.38
S7	0.24	0.41	70	75	10.81	9.70
S8	0.46	0.61	30	25	12.99	12.51
S9	0.38	0.66	42	20	12.18	11.68
S10	0.16	0.23	60	70	6.27	5.44
S11	0.89	1.04	-	-	12.96	10.68
Mean± Std. Dev	0.34±0.27	0.62±0.45	54.4±19	48.6±23.77	10.79±3.17	9.05±3.31
Overall mean± Std. Dev	0.48±0.38		51.5±21.16		9.92±3.29	

Relatively high Secchi depth (Z_{SD}, cm) was recorded at the site of S1 in dry and rainy season. The low value of Secchi depth (Z_{SD}, cm) was recorded at the site of S5 during this study period (Table 3). The overall mean of Secchi depth (Z_{SD}, cm) was recorded at 51.59 (Table 3). There was a statically significant difference among the sites ($P < 0.05$, Table 4). The Secchi depth of the presented study was higher than the previous report (35.4 cm) by Ayalew et al (2007). A low value of Secchi depth was recorded at site S5 where the river Abay entered the Lake. This might be due to the loam soil and organic particulates carried by runoff.

Table 4: P-value of Chlorophyll-a (Chl-a), Total phosphorus (TP) and Secchi depth (Z_{SD})

Parameters	**Sum of Squares**	**Mean Square**	**F**	**P-value**
Chlorophyll-a (Chl-a)	154.260	15.426	2.328	0.091
Total phosphorus (TP)	1.677	0.168	1.242	0.362
Secchi depth (Z_{SD})	7747.000	860.778	11.356	0.000*

* Indicates significant at the 0.05 level

Chlorophyll-a of algae (Chl-a)

The chlorophyll-a concentration varied slightly varied both spatially and temporally at different sites in Lake Tana during the study period. Chl-a concentration at site S2 was relatively high in the dry and rainy season. The minimum Chl-a concentration was recorded at the site of S10 during the dry season. In the rainy season, the minimum concentration was at S5 (Table 3) but the difference in (Chl-a) each site was not statically significant at $P > 0.05$ (Table 4). In Lake Tana, the overall mean Chl-a concentration was 9.92 μgL^{-1} for the dry and wet seasons combined (Table 3). The present mean chlorophyll-a biomass was slightly greater than the previous reported biomass of chl-a (2.6-8.5 μgL^{-1}, Ayalew et al., 2007). As a result, the lake may have a high amount of nutrients from fertilizers, septic systems, sewage treatment facilities, and urban runoff.

Estimation of the trophic state index of Lake Tana

The total phosphorus trophic state index (TSI_{TP}) value suggested that Lake Tana was at a hypereutrophic state while Secchi depth trophic state index (TSI_{SD}) and chlorophyll-a (TSI_{chl}) was implied strongly mesotrophic (Table 5 and Table 2). Thus, trophic state index value (TSI_C) of 65.63 was obtained for Lake Tana. Lake Tana is a eutrophic lake and is found near the upper border of the Eutrophic level, according to the indices of the classification system for trophic states (Carlson 1977). Goraw et al (2017) predicts that the trophic state of Lake Tana has gradually changed from mesotrophic to Eutrophic in some places due to the nutrient load. Thus, the cause of the eutrophic state of a Lake Tana could be the input of high nutrient load from the catchment by erosion. However, Lake Tana was previously described as mesotrophic with low chlorophyll content and primary production according to the tropical lake's standard (Ayalew et al 2007; Yirga and Hassen 2015).

Table 5: Estimated value of the trophic state index of Lake Tana.

Parameters used	Trophic State Index (TSI)	Values estimated for the Lake Tana	Trophic state Category
Secchi depth (Z_{SD})	TSI_{SD}	50.42	Strongly mesotrophic
Total phosphorus (TP)	TSI_{TP}	93.38	Hypereutrophic
Chlorophyll-a (Chl-a)	TSI_{Chl}	53.10	Strongly mesotrophic
	TSI_C	65.63	Hypereutrophic

4. CONCLUSION AND RECOMMENDATION

Lake Tana could be described as strongly mesotrophic using both chlorophyll-a and Secchi depth trophic state index. However, the total phosphorus trophic state index indicated that Lake Tana was Hypereutrophic Lake. In general, Lake Tana might be classified as Hypereutrophic based on the average of three trophic status indicators, indicating that high total phosphorus may be introduced into the Lake by erosion from agricultural practices, residential and urban effluents. The different development activities being carried out in the vicinity of its shores and in the catchment, area might be the possible cause of increased total phosphorus that could make Lake Tana to be eutrophic lake. As a result, high phosphorus concentrations must be minimized by delineated and protected lake buffer zones, as well as some practical mitigation and control measures done by the responsible bodies in partnership with the local population. Therefore, it is recommended to carry out continuous limnological studies to closely monitor the lake water quality so that some remedial actions could be taken.

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