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Trend of Phytoplankton Composition and Physicochemical Water Quality Parameters of Lake Hayq, Ethiopia

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ABSTRACT

The study was conducted in Lake Hayq between January and December, 2018. The objectives of the study were to assess the trend of phytoplankton composition, biomass, and physicochemical water quality parameters for last ten years. Integrated and net water sampling methods were used to collect phytoplankton and physicochemical water quality parametres. The collected data were analyzed using multivariate Analysis (Two Way ANOVA and Redundancy Analysis) using SPSS Version 16 and CANOCO 4.5 Software. Lake Hayq had higher mean water temperature (23 ^oC), pH (85-9.0), average Secchi disk depth (3.5 m), turbidity (<5 NTU), mean total alkalinity (8.8 meqL^{-1}), mean Total phosphorus (39 µgL^{-1}), Soluble Reactive Phosphorus (8.3 µgL^{-1}), Nitrate (177.1-181.8 µgL^{-1}), Silicon dioxide (142.3 µgL^{-1}), mean Chlorophyll-a (4.03 µgL^{-1}) and mean conductivity (920 µScm^{-1}). There was no significant species composition change in the last ten years, a total of 44 phytoplankton species grouped under six divisions, Chlorophyta, Bacillariophyta, Cyanophyta, Euglenophyta, Dinophyta, and Cryptophyta were recorded. Chlorophyta and Bacillariophyta were dominant groups in terms of species composition. *Peridinium*, member of Dinophyta was the most abundant species in most of the sampling seasons and sites for the first time which seem to be favored with atelomixis, partial mixing of Lake Hayq. Based on Carlson's index of trophic state, Lake Hayq was mesotrophic with Carlson's index of trophic state value of 47.72 which was the actual average of TP, SD and Chlorophyll-a. Lake Hayq had more inorganic nutrient value due to nutrient enrichment through runoff, siltation and point source of pollution from nearby Lodges which may accelerate eutrophication process in near future. Therefore, integrated watershed management should be implemented to minimize the nutrient load and restore the lake.

Key Words: Nutrients; Chlorophyll-a; Mesotrophic; *Peridinium*; Phytoplankton Net; Trophic State

INTRODUCTION

Phytoplankton are important primary producers and are at the base of the food chain. They are also recognized as bio-indicator organisms in the aquatic environment due to their short generation time and fast response to changes in aquatic environment such as nutrient enrichment, and they can be used as early warning indicator (Hassan et al. 2013, Agnieszka 2016).

Phytoplankton composition, distribution, and density are good indicator of trophy. Their composition, growth, abundance and dynamics in lakes are collectively influenced by environmental variables (physical, chemical and biological properties of water), especially nutrient enrichment, water transparency, temperature and biotic interactions such as predation and competition (Ariyadej et al. 2004, Nowrouzi and Valavi 2011, Ogbuagu et al. 2011, Dayala et al. 2014, Patil et al. 2015, Fekadu and Chanie 2017). Phytoplankton is the most sensitive aquatic community and any undesirable change in aquatic ecosystem affects diversity as well as biomass of the community (Wondie et al. 2007, Manjare et al. 2015)

Phytoplankton does not only produce oxygen and food but also use ammonia produced by fish as nutrient. some species such as Cyanobacteria, on the other hand, can be harmful to human, and other animals by releasing toxic substances (hepatotoxins or neurotoxins etc) into the water (Carmichael 2001, Kaihong et al. 2006, Malbrouck and Kestemont 2006, Chapman and Ronberg 2008, Hassan et al. 2013).

Knowledge on phytoplankton ecology is important for freshwater lake management. The relationship between chlorophyll-a and nutrients in limnology has been studied extensively, as such study provide insight into the relative importance of chemical, physical and biological constraints on phytoplankton biomass in water bodies (Kuo et al. 2007).

Algal biomass can be limited by nitrogen, phosphorus or by physical factors such as temperature or light in lakes and reservoirs (Vörös and Pandisak 1991, Dzialowski et al. 2005). Nitrogen and phosphorus are generally described as driver variables of chlorophyll-a and Secchi disk depth in lakes and reservoirs (Soballe and Kimmel 1987, Kagalou et al. 2008).

Lake Hayq is a highland lake that has significant ecosystem services such as, drinking water, fishery, tourism, water for irrigation and livestock watering. The lake has been changed from oligotrophic to eutrophic state after the introduction of Nile tilapia (*Oreochromis niloticus*) in 1970s (Kebede et al. 1992, Fetahi et al. 2011). Lake Hayq has been affected by anthropogenic and natural factors, invasive plant species (Tamrie et al. 2016), overfishing (Tessema and Geleta 2013, Tewabe et al. 2015, Seid 2016), pollution (Teklay and Amare 2015, Ruchi et al. 2016), land use/ land cover change and reduction in water volume (Mohammed et al. 2013; Melaku and Shiferaw 2014), siltation (Mohhamed et al. 2013, Melaku and Shiferaw 2014) and rainfall variability and climate change (Melaku and Shiferaw 2014). Thus, the ecology of the ecosystem of Lake Hayq might have been changed.

Various aspect of the lake has been investigated by several authors (phytoplankton ecology, fish biology, hydrology, land use, and land cover in and around as stated in aforthmentioned. However, there was no recent study that demonstrates the present status of the phytoplankton composition, biomass and physicocmecial water quality parametres . Therefore, this study was initiated to assess the phytoplankton composition and biomass of the Lake Hayq in relation to the physicochemical water quality parameters. The paper attempts to compare the present findings with the historical data. Furthermore, we determine the trophic status of Lake Hayq using tropical suited model to characterize the current ecological condition of the lake.

STUDY AREA

The study was conducted in Lake Hayq. Lake Hayq is located in the North Central highlands of Ethiopia. It is a typical example of highland Lake of Ethiopia with volcanic origin. Geographically, it lies between 11^0 3' N to 11^0 18' N latitude and 39^0 41' E to 39^0 68' E longitude with an average elevation of 1911 meter above sea level. The lake has a closed drainage system and the total watershed area is about 77 km^2 of which 22.8 km^2 is occupied by Lake Hayq. According to Demllie et al. (2007), the average depth of the lake is 37 m, and the maximum depth is 81 m. The only stream entering the lake is the Ankerkeha River, which flows into its southeastern corner. According to Fetahi et al. (2011), Lake Hayq is classified as a small highland freshwater lake (Figure 1).

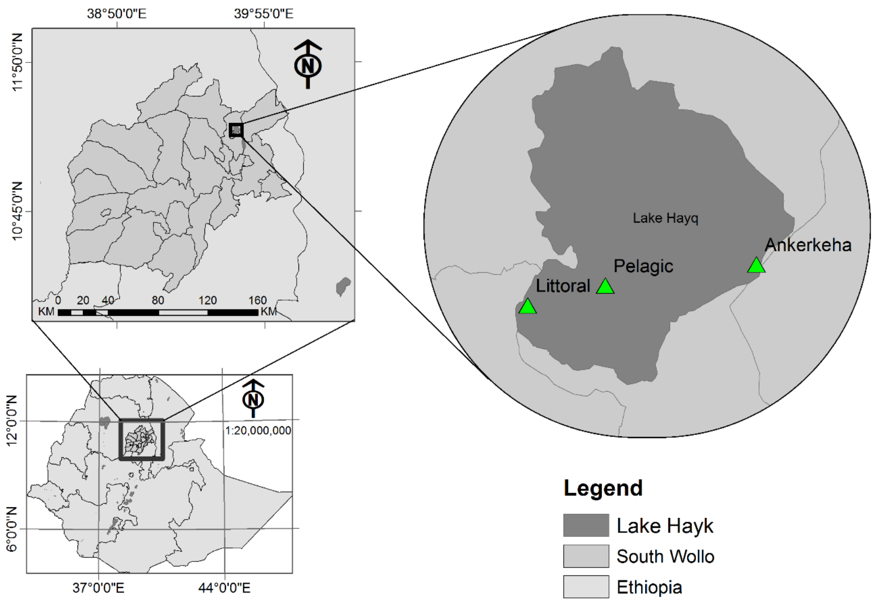

Figure 1: Location map of Lake Hayq with respect to Ethiopia and Amhara Regional State

Climate

Among the climate variables, only maximum and minimum temperature and rainfall of Lake Hayq were available at Kombolcha Meteorological Agency. In 2018, the average monthly maximum and minimum temperature around Lake Hayq was 25.9 and 9.9 ^{o}C, respectively. The mean maximum temperature was highest in June and lowest in January. The highest and the lowest mean monthly rainfall were recorded in August and May, respectively (Figure 2). The annual rainfall was 1200 mm. The rainfall and the temperature variability around Lake Hayq for the last 10 years (2009-2018) were very low. In these years, the average monthly minimum and maximum temperature and annual rainfall were 9.8^{o}C, 26.6 ^{o}C and 1205.6 mm, respectively (Kombolcha Meteorological Agency 2019).

METHODS

Sampling Sites

Three sampling sites, Littoral (close to Lodges and intensive humans and livestock activities), Pelagic (open water, relatively less pressure from human activities) and Ankerkeha River Mouth (big river that brings sediments to the lake) were selected (Table 1).

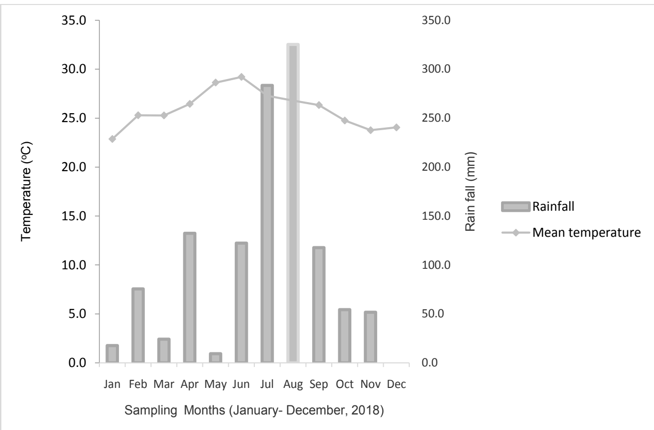

Figure 2: Mean monthly rainfall and mean maximum monthly temperature in Lake Hayq (Kombolcha Mereological Agency 2019)

Table 1. Sampling site description

Sampling sites	Characteristics	Depth (m)	Altitude (m)	Coordinate points (UTM) X	Y
Ankerkeha River Mouth	Silt load	5.3	1900	579715.383	1253117.123
Pelagic	Open water (less impact)	55.4	1907	576688.51	1252693.02
Littoral	Near Lodges (more pressure)	6.3	1903	575131.78	1252295.8

Physicochemical Water Quality

Physicochemical water quality parameters (Temperature, conductivity, and pH) were measured using Wagtech Portable digital Multi-meters, transparency was measured with Secchi disk (20 cm diameter) and dissolved oxygen (DO) with SX725pH/mV/DO meter in situ. Turbidity of the lake water was measured using a portable digital turbidimeter (Model Oakton: T-100). Water samples were collected from Lake Hayq using plastic sampling bottles for chemical analysis (nutrients) based on standard procedures (APHA 1995). The sample bottles were immediately kept in an ice-cooled box and transported to Addis Ababa University laboratory for Chemical analyses (Soluble Reactive Phosphorus-SRP, Total Phosphorous-TP, dissolved silicate-SiO_2, nitrite-NO_2, and nitrate-NO_3) were analyzed with spectrophotometer in Pre-rainy (April-June), Rainy (July-September), Post-rainy (October-December) and dry (January-March) seasons between January and December, 2018.

In the Laboratory, total alkalinity was determined from 100mL of the unfiltered water sample taken from the surface by titration with 0.1N HCl with bromocresol green used as endpoint indicator (Wetzel and Likens, 2000). The major dissolved inorganic nutrients (soluble reactive phosphorus, total phosphorous, dissolved silicate, nitrite, and nitrate, were determined using the standard method of APHA (1995) (Table 2).

Table 2. Standard method for determining inorganic nutrients (after APHA 1995)

Nutrients	Method
SRP	Ascorbic Acid
TP	Unfiltered water digested using potassium–peroxodisulphate, and autoclaved at 120 ^{o}C for 50 minutes then follow SRP procedure
SiO_2	Molybdosilicate
NO_2^-	The reaction between sulfanilamide and N naphthyl-(1)-ethylenediamine dihydrochloride
NO_3^-	Sodium salicylate

Trophic State Determination

The Trophic state of Lake Hayq was determined using Carlson (1977) trophic status index (TSI) determination method for an inland water body, which was calculated based on Secchi disk depth (SD), chlorophyll-a content (Chl-a), and concentration of total phosphorus (TP).

Carlson (1977) trophic state equation:

TSI SD = 60-14.41 (lnSD) …Eq. 1

TSI TP = 14.41 ln (TP) +4.15. …Eq. 2

TSI Chla = (9.8) (ln CHLA) +30. 6 …Eq. 3

TSI_C (Average) = (TSI-SD+TSI-TP +TSI-CHLA)/3. …Eq. 4

Where, TSI stands for trophic state index, TSIc for Carlson's trophic state index, ln for natural logarithm, SD for Secchi Depth (meter), TP for total phosphorous (μg L-1), and Chla for chlorophyll-a (μg L-1). From this equation, Carlson's estimated the trophic state values ranging for Oligotrophic lakes (TSI, <40), Mesotrophic (TSI, 40-50), Eutrophic (TSI, 50-70), and Hypereutrophic (TSI, >70) state

Phytoplankton Data

Net sampling from the euphotic zone was done for phytoplankton using 15μm in four seasons (pre-rainy, rainy, post-rainy and dry seasons). The phytoplankton samples were preserved with Lugol's solution in the field. After preservation, determination of abundance and diversity of phytoplankton were done with inverted microscope and compound microscope in Addis Ababa University and Wollo University.

Phytoplankton Biomass

Phytoplankton biomass was estimated as chlorophyll-a concentration spectrophotometrically from water samples filtered through glass filters (GF/C). Chlorophyll-a was extracted from the phytoplankton concentrate with aqueous acetone (90%). The filters were manually ground with a glass rod to enhance extraction of pigments. The concentration of chlorophyll-a was calculated using absorbance measurements made at 665 and 750 nm (Talling and Driver 1963).

RESULTS

Physicochemical Water Quality Parameters

Lake Hayq is a slightly alkaline system with a mean total alkalinity of 8.8 meq L^{-1} and a pH range of 8.5-9.0 almost similar in all sampling sites and seasons. Electrical conductivity also fluctuated little with a mean of 920 μScm^{-1}. The minimum dissolved oxygen (DO) recorded was 6.29 mg L^{-1} (91.5 % saturation) during pre-rainy season at 20 m depth in pelagic part of the lake. During all four seasons (pre-rainy, main rainy, post rainy and dry season), there was no stratification in Lake Hayq. The multivariate analysis showed that there was significant difference in DO, temperature, Conductivity, Secchi disk and Chlorophyll a ($P<0.05$) within seasons and sampling sites unlike turbidity and pH ($P>0.05$) (Table 3).

Depth Profiles of Temperature and Dissolved Oxygen

Temperature: Water temperature and DO varies with depth and seasons in Lake Hayq. The maximum water temperature at the deepest depth (20m) at the open-water site ranged from at 22.6-23.8 ^oC during pre-rainy season and minimum values were ranged from 21.4- 22.2 ^oC during dry season. In Lake Hayq, the temperature difference along the depth profile was very low (< 1 ^oC). Dissolved oxygen (DO): In Lake Hayq, except rainy season, all depth profiles showed the maximum oxygen record in the upper layer of the water column and it declined with increasing depth. During the study period, the concentration of dissolved oxygen at the maximum depth (20 m) showed temporal variations from 6.29 mg L^{-1} in pre-rainy season and to a maximum of 7.47 mg L^{-1} O_2 in rainy season at the open water site.

Phytoplankton Biomass in Lake Hayq

Biomass of phytoplankton measured in (μgL^{-1}) varied seasonally and among the sampling sites. The highest mean phytoplankton biomass (6.16 ±0.8) was recorded at littoral site during rainy season and the lowest (2.33± 0.7) was recorded at Ankerkeha site during pre-rainy and post rainy seasons as (Table 3).

Inorganic Nutrients

The major inorganic nutrients analyzed in the present study were nitrogen (NO_2^-, NO_3^-, NH_3), phosphorus (SRP and TP), and dissolved silicate (SiO_2). The concentrations of each of the measured nutrients are indicated in Table 4. There was significant variation in inorganic nutrient concentration among sampling sites in four seasons (Dry, Pre-rainy, Rainy and Post-rainy) ($P < 0.05$). The concentation value of these inorganic nutrients were higher at the mouth of Ankerkeha River (Table 4).

Table 3. Monthly physicochemical parameters (means and standard deviation, SD) measured a three sampling sites (Ankerkeha, Pelagic, and Littoral)

		Seasons			
		Dry	Pre-Rainy	Rainy	Post-Rainy
Parameters	Sites	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
DO (mg L^{-1})	Ankerkeha	6.9 ±0.1	7.5 ±0.1	7.7 ±0.0	6.7 ±0.0
	Littoral	7.0 ±0.1	7.9 ±0.3	8.0 ±0.1	6.9 ±0.2
	Pelagic	6.8 ±0.3	7.3 ±0.6	7.4 ±0.1	6.8 ±0.2
Temperature (^{0}C)	Ankerkeha	21.8 ±0.5	23.4 ±0.3	23.7 ±0.9	23.2 ±0.4
	Littoral	22.3 ±0.2	23.9 ±0.2	24.7 ±0.4	23.2 ±0.6
	Pelagic	21.9 ±0.3	23.3 ±0.5	22.8 ±0.2	23.0 ±0.7
pH	Ankerkeha	8.7 ±0.0	8.9 ±0.2	7.7 ±0.1	8.9 ±0.0
	Littoral	8.8 ±0.00	9.0 ±0.1	7.8 ±0.1	8.9 ±0.1
	Pelagic	8.8 ±0.0	8.9 ±0.1	7.8 ±0.0	9.0 ±0.0
Conductivity (µS cm^{-1})	Ankerkeha	904.3 ±6.2	864.2 ±25.2	900.0 ±50	848.5 ±11.8
	Littoral	885.8 ±22.2	849.8 ±26.7	944.0 ±95.9	852.3 ±17.7
	Pelagic	900.0 ±29.5	869.4 ±15.1	952.5 ±67.2	861.0 ±9.1
Secchi Disk (m)	Ankerkeha	1.7 3±0.5	3.8 ±0.4	3.12 ±0.5	3.75 ±1.2
	Littoral	1.27 ±0.4	3.34 ±0.5	3.64 ±0.5	3.42 ±1.1
	Pelagic	1.92 ±0.1	4.49 ±1.5	3.13 ±0.8	3.82 ±0.8
Chl-*a* (µg L^{-1})	Ankerkeha	3.56 ±0.8	2.33 ±0.7	4.81 ±0.2	2.33 ±0.7
	Littoral	5.01 ±1.4	2.87 ±1.9	6.16 ±0.8	2.87 ±1.9
	Pelagic	4.50 ±1.1	4.3 ±0.5	5.35 ±1.7	4.3 ±0.5
Turbidity (NTU)	Ankerkeha	2.7 ±1.5	3.6 ±0.9	4.27 ±0.7	3.75 ±0.1
	Littoral	2.27 ±1.2	4 ±0.5	4.20 ±1.8	3.07 ±1.3
	Pelagic	1.9 ±0.6	2.57 ±0.3	2.86 ±1.0	2.47 ±0.8
Total alkalinity (meq L^{-1})	Ankerkeha	8.63 ±0.12	8.73 ±0.16	9.4 ±0.17	8.8 ±0.27
	Littoral	8.8 ±0.17	8.83 ±0.31	9.2 ±0.46	9.03 ±0.5
	Pelagic	8.9 ±0.27	8.63 ±0.16	9.21 ±0.58	8.9 ±0.3

Table 4. Spatial and temporal variation of algal nutrients of Lake Hayq

		Seasons			
		Dry	Pre-Rainy	Rainy	Post-Rainy
Parameters	Sites	Mean ±SD	Mean ± SD	Mean ± SD	Mean ± SD
NO_2 (µg L^{-1})	Ankerkeha	133.2 ±6.3	134.5 ±13.3	90.0 ±7.7	138.6 ±11.5
	Littoral	127.8 ±4.8	110.0 ±16.8	134.7 ±6.7	121.6 ±6.9
	Pelagic	126.8 ±1.5	125.6 ±15.4	52.2 ±54.3	90.6 ±7.7
NO_3 (µg L^{-1})	Ankerkeha	181.8 ±0.0	151.4 ±1.5	164.9 ±1.3	161.9 ±7.14
	Littoral	166.6 ±0.8	151.4 ±0.8	161.0 ±0.0	147.1 ±1.3w
	Pelagic	172.7 ±1.3	164.9 ±0.0	159.6 ±1.3	147.1 ±0.0
NH_3 (µg L^{-1})	Ankerkeha	36.1 ±5.5	79.3 ±1.0	19.3 ±3.6	37.8 ±3.7
	Littoral	15.1 ±1.0	42.7 ±9.3	19.3 ±3.6	22.8 ±1.8
	Pelagic	13.3 ±3.7	70.9 ±2.2	33.7 ±.00	24.6 ±0.0
SiO_2 (µg L^{-1})	Ankerkeha	203.1 ±0.2	183.1 ±0.2	201.0 ±0.3	175.0 ±1.6
	Littoral	200.5 ±0.4	184.6 ±0.2	198.2 ±0.3	55.3 ±2.5
	Pelagic	199.1 ±0.2	183.9 ±1.4	200.6 ±0.0	181.7 ±7.5
SRP (µg L^{-1})	Ankerkeha	12.6 ±3.0	4.9 ±0.1	0.7 ±0.1	2.7 ±0.0
	Littoral	6.8 ±0.5	2.3 ±0.1	0.5 ±0.0	2.7 ±0.0
	Pelagic	9.3 ±0.5	3.4 ±1.0	0.5 ±0.01	2.0 ±0.13
TP (µg L^{-1})	Ankerkeha	31.3 ±0.5	80.2 ±1.5	2.6 ±0.1	31.5 ±3.1
	Littoral	34.4 ±0.0	53.1 ±1.2	2.9 ±0.0	27.2 ±1.95
	Pelagic	19.1 ±0.0	32.0 ±0.1	0.9 ±0.0	18.6 ±1.18

Trophic Status of Lake Hayq

The trophic status index of Lake Hayq based on total phosphorus (TP), Secchi-disk depth (SD) and Chlorophyll-a (Chl-a) is presented in Table 5. The trophic status index value based on Secchi disk-depth value was lower (41.95) than the trophic status index value based on total phosphorus (56.94) and chlorophyll-a (44.26). The Carlson's trophic state index value was 47.72, therefore, Lake Hayq was in mesotrophic state (40-50) (Table 5).

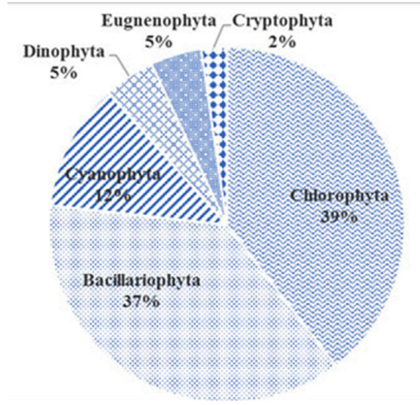

Figure 3. Species composition of Lake Hayq

Table 5. Trophic Status Index of lake Hayq

TP	TSI (TP)	Secchi-disk depth	TSI (Sec)	Chl-a	TSI Chl-a	TSIc
39	56.94	3.5	41.95	4.03	51.46	43.16

Phytoplankton Composition

A total of 44 phytoplankton species classified under Chlorophyta (17), Bacillariophyta (16), Cyanophyta (5), Dinophyta (2), Euglenophyta (2) and Cryptophyta (1) were recorded in Lake Hayq. Chlorophyta (39%), Bacillariophyta (37%) and Cyanophyta (12%) were algal groups comprising the maximum species composition (Figure 3) and (Table 6).

Phytoplankton Abundance

Among the phytoplankton taxa identified from Lake Hayq, Dinophyta and Cryprophyta were the most and the least dominant groups (Figure 4). Dinophyta, Chlorophyta and Bacillariophyta were the dominant groups in abundance. Dinophyta were dominant in all seasons and sites. The abundance of Dinophyta were recorded in pelagic site in all the four seasons (Dry, post-rainy, Pre-rainy and Rainy seasons). However, there was no distinct variation of Bacillariophyta and Chlorophyta among sampling sites and seasons (Figure 4).

Redundancy Analysis (RDA)

The correlation of the environmental fvariables (Oxygen saturation, DO, NO_2, NO_3, NH_3, NH_4, SRP, TP, Chlorophyll-a, Secchi-disk depth,, pH,

Table 6. Phytoplankton composition of Lake Hayq

Cyanoprocaryota	Chlorophyta	Bacillariophyceae	'Others group'
Microcystis flos-aquae	*Arthrodesmus*	*Fragilaria* sp.	**Cryptophyta**
M. aeruginosa	*Coelastrum astroideum*	*Navicula*	*Cryptomonas*
Merismopedia	*Cosmarium* sp.	*Aulacoseira*	**Dinophyta**
Anabena sp.	*Oocystis*	*Cymbella aspera*	*Peridinium*
Oscillatoria	*Pediastrum simplex*	*Cymbella cf helvetica*	*Gymnodinium*
	P. duplex	*Epithemia adnata*	**Euglenophyta**
	Pediastrum boryanum	*Gomphonema* sp.	*Euglena* sp.
	Scenedesmus sp.	*Halamphora coffeaeformis*	*Phacus* sp.
	S. quadricauda	*Gyrosigma* sp.	
	Closterium	*Cyclotella regtangulare*	
	Tetraedron minimum	*Nitzschia* sp.	
	Staurastrum cingulum	*Surirella robusta*	
	Staurastrum uplandicum	*Surirella angusta*	
	Staurastrum obesum	*Synedra* sp.	
	Volvox	*Amphora strigosa*	
		Rhopalodia sp.	

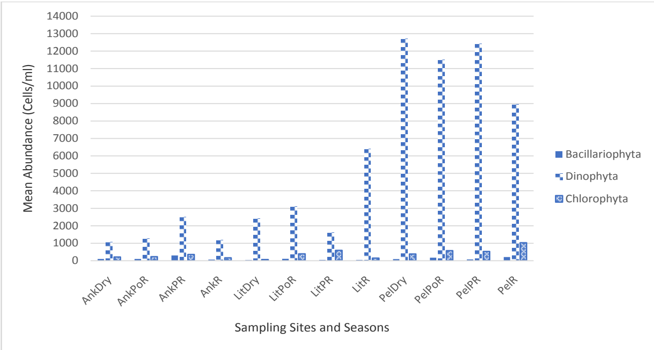

Figure 4: Spatial Variation of Major divisions of phytoplankton in Lake Hayq (AnkDry, Ankerkeha site in dry, AnkPoR, Ankerkeha in post-rainy, AnkPR, Ankerkeha in pre-rainy, AnkR, Ankerkeha in rainy, LitDry, Littoral in dry, LitPoR, Littoral in Post-rainy, LitPR, Littoral in Pre-rainy, LitR, littoral in Rainy, PelDry, Pelagic in dry, PelPoR, Pelagic in Post-rainy, PelPR, pelagic in Pre-rainy and PelR, Pelagic in rainy seasons)

Conductivity and Temperature) with mean abundance of the dominant phytoplankton species (*Cymbella*, *Coscinodiscus*, *Nitzschia*, *Cosmarium, S. uplandicum, Cyclotella, Gymnodinium, Anabaena, Staurastrum* species, *Phacus, Fragillaria, S. cingulum, Surirella, M. aeruginosa, Arthrodesmus, Oocystis, Tetradron, M. flosaquae, Peridinium, E. adnata, Aulacoseria, Rhopalodia* and *Synedra*) in sampling sites (Littoral, Pelagic and Ankerkeha) of Lake Hayq was analyzed using a constrained Redundancy Analyses (RDA, CANOCO 4.5 software). The environmental parameters and phytoplankton species were positively correlated in Littoral and Ankerkaha sites unlike the Pelagic site (Figure 5). For example, Dissolved Oxygen, oxygen saturation, Temperature, Conductivity, Chl-a, and Secchi-disk depth were positively correlated with *Rhopalodia, Aulacoseria, Epithemia* and *Peridinium* species. The first and second axes together explained 100% of the

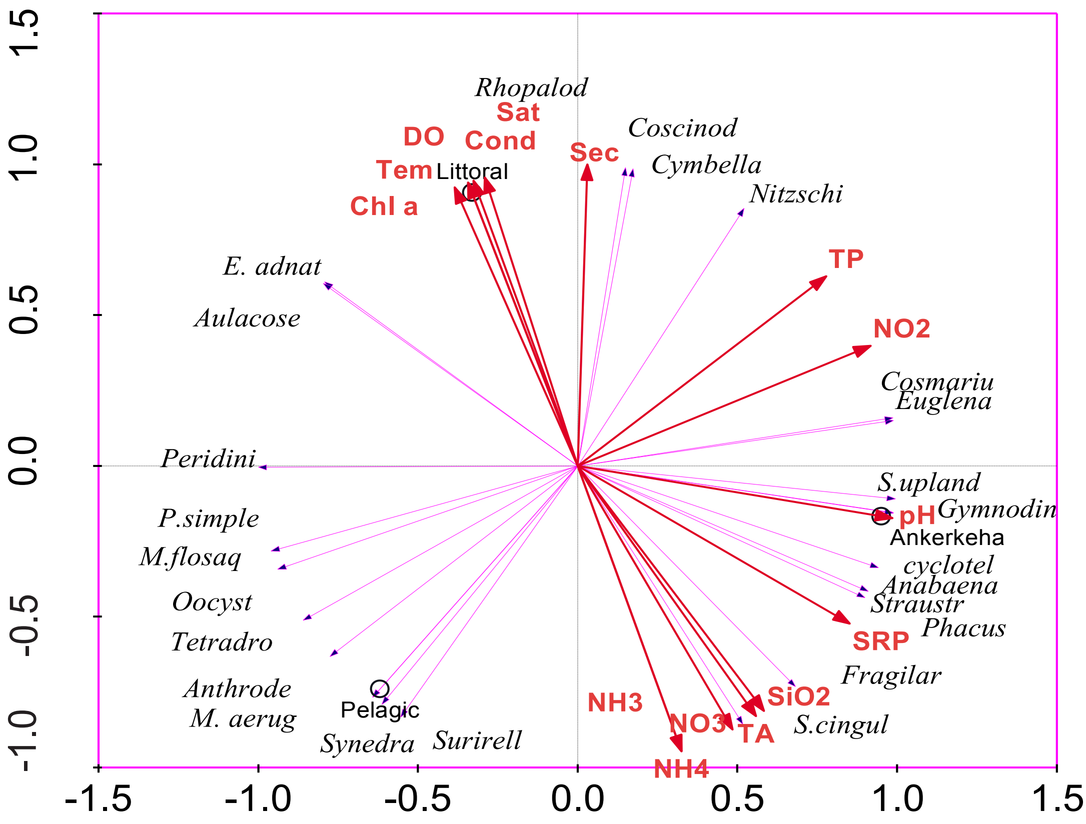

Figure 5. Tri-plot of the Redundancy Analyses (RDA) for dominant phytoplankton species (purple arrow and environmental variables (red arrows) and Black circle (Sampling sites, Pelagic, Ankerkeha, and Littoral): Coscinod-*Coscinodiscus*, Nitzschi-*Nitzschia*, Cosmariu-*Cosmarium*, S.upland-*S.uplandicum*, Gymnodin-*Gymnodinium*, Cyclotel *Cyclotella*, Straustr-*Straustrum*, Fragilar-*Fragilaria*, S. cingil, *S. cingulum*, Surirell-*Surirella*, Synedra, M. aerug- *M.aeruginosa*, Anthrode-*Anthrodesmus*, M. flosaq-*M. flosaquae*, P. simple- *P. simplex*, Peridini-*Peridinium*, Aulacose-*Aulacoseria*, E. adnat- *E. adnata*, Rhopalod-*Rhoplalodia*, TP-total phospurus, NO_2, pH, SRP-Soluble reactive phosphorus, SiO_2, TA-total alkalinity, NO_3, NH_3, NH_4+, Chl a- chlorophyll a, Tem-Temperature, Do-dissolved oxygen, Cond-conductivity and Sat-Oxygen saturation

cumulative percentage variance of species-environment relations (Table 7). The first axis explained 96.2% and the second axis explained 3.8% of species-environment relations (Table 7). The environmental parameters (pH, NO_2^-, NO_3^-, NH_3, NH_4+, SiO_2, SRP, TP) had strongly positive correlation with Axis1 but Some of the parameters (DO, Saturation, Temperature, Conductivity, Secchi disk depth, NO_2, TP and chlorophyll-a) had strong positive correlation with Axis 2

DISCUSSION

Physicochemical Water Quality Parametres

Lake Hayq is a highland lake with a mean depth of 31m, and 81m maximum depth. Though, the lake is located in the highland (about 1900 m), the average surface water and deeper layer water temperature varied between 24 ^{o}C and 20 ^{o}C, respectively, which is higher than most highland lakes in Ethiopia. For instance, lower surface and deeper layer water temperatures of 16.7 and 14.9 ^{o}C, respectively were recorded for highland lakes of Dendi and Wonchi (Degefu et al. 2014). Vijverberg et al. (2012) have measured the mean surface temperature of around 18.5 and 20 ^{o}C for Lake Hashenge and Tana. The unusual higher temperature in Lake Hayq might have been the result of volcanic activity (Vijverberg et al. 2012). The pH of Lake Hayq was within the range of 8.5 to 9.6 where CO_3^- is dominant and these values were greater than Lakes Dendi, Wonchi, and Ziqualla (7.91- 8.27) where HCO_3^- is dominant. The mean total alkalinity of Lake Hayq varied between 8.63 ± 0.12 and 9.4 ± 0.17 which was almost similar to earlier reports made for the same lake (Fetahi et al. 2014). Total alkalinity concentrations for natural waters may range from 0 mg L^{-1} (very low) to more than 500 mg L^{-1} (very high) (Boyd 2000).

Table 7. Summary of the statistics of the RDA (Redundancy Analysis)

Axes	1	2	3	4
Eigen values	0.962	0.038	0	0
Species-environment correlations	1	1	0	0
Cumulative percentage variance of Species data:	96.2	100	0	0
Of species-environment relation:	96.2	100	0	0
Sum of all eigenvalues	1			
Sum of all canonical eigenvalues	1			

In the present study, the Secchi-disk depth value varied with seasons and sampling sites. The highest mean value (4.49 ± 1.5 m) was recorded at Pelagic site during the Pre-rainy season and the lowest value (1.27± 0.4 m) was measured at the Littoral site during dry season. Generally, the mean Secchi-disk depth value of Lake Hayq in the current study was nearly 3.5 meters giving an euphotic depth of > 10 m and a mean chlorophyll-a value of 4.03µgL^{-1}. The Secchi-disk depth value measured by different scholars in Lake Hayq were different at different times and they related the values with the introduction of Nile tilapia in 1978. Before the introduction of the fish, the lake was very clear with an average Secchi-disk depth of 9 m and < 1 µgL^{-1} chlorophyll-a concentration (Baxter and Golobitsch 1970). However, Kebede et al. (1992) reported a very low Secchi-disk depth value of 1.2 m and relatively high chlorophyll-a of 17µg L^{-1}, which might be associated with the change of trophic status of Lake Hayq from Oligotrophic to Eutrophic state. The trophic status change of Lake Hayq was also confirmed by Fetahi et al. (2014) that have reported mean Secchi disk depth (0.8- 6.3 m) and Chlorophyll-a (12.9 µg L^{-1}) from their 2007/2008 data collected. The higher algal biomass and seasonal change and persistent occurrence of heavy taxa in Lake Hayq were influenced by atelomixis, partial mixing (Fetahi et al. 2014). On the other hand, very low chlorophyll-a (<5 µg L^{-1}) and a higher Secchi-disk depth value of 5 meters were reported by Vijverberg et al. (2012) from their 2004/2005 snapshot survey. As indicated in Vijverberg et al. (2012), the higher water temperature in a deeper layer might be due to geothermal activities in the bottom layer that may contribute to vertical mixing seasonally and increase nutrients for excessive phytoplankton growth (eutrophication) temporarily. In the present study, the mean Secchi-disk depth (3.5 m), mean chlorophyll-a (4.03 µg L^{-1}) and TSIc value (47.72) showed that the lake is mesotrophic. The change in trophic status of Lake Hayq might be due to common carp invasion which has grazing effect on phytoplankton as observed from gut content analysis of common carp (Tessema, Unpublished, 2018) and sedimentation of the Lake Hayq through Ankerkeha River (Mohammed et al. 2015).

Phytoplankton Composition, Abundance and Inorganic Nutrients

In the 1940s, Lake Hayq was dominated mainly by *M. flosa-aquae*, *M. aeruginosa*, *Phormidium* and *Peridinium* and some heavy diatoms such as *Gomphonema* and *Epithemia* species, but since the 1990s, other phyto-plankton groups and taxa have become relevant

(Zanon 1941, Cannicci and Almagia, 1947, Baxter and Golobitish 1970, Fetahi et al. 2014).

In the present study, a total of 45 phytoplankton species were identified, which were grouped under six divisions: Chlorophyta, Bacillariophyta, Cyanophyta, Eugleonophyta, Dinophyta, and Cryptophyta. The number of species was slightly higher than that of Fetahi et al. (2014) who reported 40 phytoplankton species. However, the number of phytoplankton species in this study were lower than Lake Tana (61) (Akoma 2010). But, it was higher than Lakes, Dendi (16), Wonchi (26) and Ziqualla (18) (Degefu et al. 2014), all are highland lakes. In the present study, diatoms and chlorophytes were dominant in most of the sampling seasons in terms of species composition. The result of this study were similar to the study conducted by Fetahi et al. (2014). However, *Peridinium*, a member of the Dinophytes, were more abundant than other species of phytoplankton in Lake Hayq. The higher abundance of *Peridinium* in Lake Hayq could be associated with atelomixis, partial mixing of the lake that seem to favor the taxa due to their special adaptation mechanisms (presence of flagella and mixotrophic feeding habits) (Barbosa and Padisak 2002, Souza et al. 2008). The lower value of Carlson's trophic state index in the current study might be due to the lower total phosphorus value and Chlorophyll-a. Typical concentrations of TP in lakes range from 10 µg/L to 80 µg/L (Wetzel 001), while in polluted waters it may reach 200 µg/L (Dodson 2005). The TP value of Lake Hayq is in the range of less polluted water bodies.

Phytoplankton Biomass

In the present study, the mean phytoplankton biomass measured in terms of Chlorophyll-a was 4.03 μgL^{-1}. This value was lower than the value (12 μgL^{-1})) reported by Fetahi et al. (2014) and 13 μgL^{-1} (Kebede et al. 1992; Gebremariam and Taylor 1997) for the same lake. However, the result of the current study was higher than other highland lakes of Ethiopia, Dendi, Wonchi and Ziqualla (Chlorophyll-a <3 μgL^{-1}) (Degefu et al. 2014) but lower than Lake Tana (Chlorophyll-a: 44 μgL^{-1}) (Tebebe et al. 2019). The mean algal biomass of Lake Hayq was also lower than rift valley lakes of Ethiopia, Lakes, Hawassa, Chamo and Ziway with mean algal biomass of 18.7± 5.2 μgL^{-1}, 29.9 ± 6 μgL^{-1} and 39.2 ± 9.4 μgL^{-1} respectively (Tilahun and Gunnel 2010).

The algal biomass of Lake Hayq was reported as low as < 1 μgL^{-1} in the 1970s (Baxter and Golobitsch). However, higher mean algal biomass (13 μgL^{-1}) was reported by Kebede et al. (1992). According to these authors, the higher algal biomass was explained by the introduction of Nile tilapia to the lake in the 1970s which had a grazing effect on zooplankton. This higher algal biomass of the lake has been confirmed by Gebremariam and Taylor (1997) with similar mean algal biomass with Kebede et al. (1992) and Fetahi et al. (2014) with mean algal biomass value of 12 μgL^{-1}).

The lower algal biomass in the present study might be due to higher water clarity and feeding competition between Nile tilapia and the accidentally introduced common carp as observed from gut content analysis of the two species (Tessema, unpublished).

CONCLUSION AND RECOMMENDATION

In conclusion, the inorganic nutrient, especially Nitrate was higher and correlated with intermediate phytoplankton biomass and abundance. The higher nitrate, total phosphorus, soluble reactive phosphorus, and silicon indicates the possibility of nutrient enrichment from runoff, solid and liquid wastes and siltation through Ankerkeha River in near future. The phytoplankton species composition was dominated by green algae followed by diatoms in species composition. In terms of numerical abundance, *Peridinium* followed by diatoms were with the highest number in most of the sampling season and sites. The higher abundance of both taxa might be associated with atelomixis (partial or incomplete mixing) of the lake. *Peridinium* has special adaptation, presence of flagella and mixotrophic feeding habits to tolerate the harsh environmental conditions during partial mixing. Based on biotic and abiotic limnological variables, Lake Hayq is categorized as a mesotrophic lake. Currently, Lake Hayq is facing major problems such as destruction of buffer zone, solid and liquid waste disposal from nearby lodges, excessive water abstraction which might contribute to water quality degradation and acceleration of cultural eutrophication. Therefore, concerned government bodies, Wollo University, Tehulederie District and other stakeholders should work together to conserve the lake.

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