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Spatial and Temporal Physicochemical Water Quality Status of Lake Hayq, Ethiopia

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Abstract

The study was conducted between January and December, 2018. The objective of the study was to assess the current status of physicochemical water quality parameters of Lake Hayq. An integrated water sampling method was used. Water quality parameters such as Dissolved Oxygen, pH, Temperature, conductivity, turbidity and Secchi-disk depth were measured in situ using digital water quality parameters and Secchi disk. Other nutrients, Nitrate, Ammonia, Total Phosphorous, Soluble Reactive Phosphorus, Silicon dioxide, Chlorophyll-a, and total alkalinity were analyzed in Addis Ababa University Limnological laboratory. Ammonium ion was analyzed in the Addis Ababa University Isotope laboratory. The collected data were analyzed using Two Way ANOVA through the application of SPSS Version 16 Software. In Lake Hayq, the mean physicochemical water quality parameters, temperature (23°C), pH (8.8), Secchi disk depth (3.5m), turbidity (4.5 NTU), total alkalinity (8.8 meqL^{-1}),Total Phosphorous (39 µgL^{-1}), Soluble Reactive Phosphorus (8.3 µgL^{-1}), Nitrate (160.90 µgL^{-1}), Ammonium ion (210 µgL^{-1}), Silicon dioxide (142.3 µgL^{-1}), Chlorophyll-a (4.03 µgL^{-1}), and conductivity (920 µS cm^{-1}) were recorded. Based on Carlson's index of trophic state (TSIC), Lake Hayq is mesotrophic (TSIC= 40.03). Lake Hayq has more inorganic nutrient value due to nutrient enrichment through runoff, siltation and point source of pollution from nearby Lodges which will accelerate the eutrophication process in the lake shortly. Therefore, integrated waste management and watershed management should be implemented to minimize the nutrient load and restore Lake Hayq.

Keywords: Chlorophyll-a; Eutrophic; Nutrients; Physicochemical parameters; Trophic state

Introduction

The quality of water in every ecosystem provides major information about the available resources for sustaining life in that ecosystem. The healthy aquatic ecosystem depends on the abiotic and biotic characteristics of water. The interactions of physical and chemical properties of water play an important role in abundance, composition, distribution, diversity, growth, reproduction and the movements of aquatic organisms. Therefore, monitoring of physicochemical parameters is necessary to recognize the magnitude and the source of any pollution load and identify the suitable environmental condition of organisms and design appropriate conservation strategies [1].

Lake Hayq is a very important highland lake that has significant ecosystem services such as, drinking water, fishery, tourism, water for irrigation and livestock watering. Lake Hayq has been changed from oligotrophic to eutrophic state after the introduction of fish species, *Oreochromis niloticus* in the 1970s [2,3].

Lake Hayq has four commercially important fish species; these are *Clarias gariepinus*, *Oreochromis niloticus*, *Garra dembecha* and *Cyprinus carpio* [4,5]. However, the lake has been affected by anthropogenic and natural factors, invasive plant species, overfishing, pollution, land use land cover change, reduction in water volume, siltation, rainfall variability, and change in temperature [6-11].

Though some studies were conducted on Lake Hayq's morphometry, water balance, physicochemical parameters, plankton structure and biology of Nile tilapia as aforementioned, most of the studies were snapshot or conducted before 10 years. Currently, Lake Hayq is being affected highly by anthropogenic and natural factors such as siltation, destruction of the buffer zone, point and nonpoint source of pollution and expansion of shoreline agriculture that might have changed the water quality of the lake. Therefore, this study aimed to assess the spatial and temporal physicochemical water quality of Lake Hayq and recommend appropriate restoration methods for the lake.

Materials and Methods

General description of the 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 lakes of Ethiopia with volcanic origin. Geographically, it lies between 11° 3'N to 110 18'N latitude and 39° 41' E to 39° 68' E longitude with an average elevation of 1911 meters 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 Molla Demlie et al. [12], 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 Tadesse Fetahi et al. [3], Lake Hayq is classified as small highland freshwater (Figure 1).

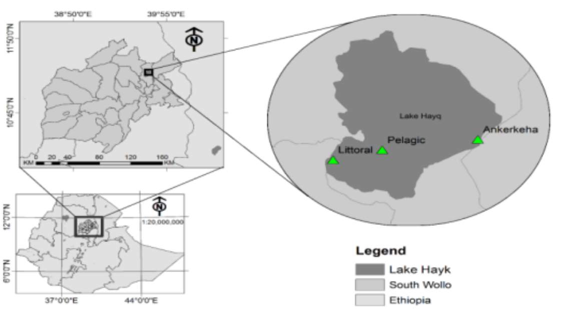

Figure 1: Location map of Lake Hayq with respect to Ethiopia and Amhara Regional State and Ethiopia.

Sampling sites and sampling protocol

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 (Largest river that brings siltation to the lake) were selected (Table 1).

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

Table 1: Sampling site description.

Sampling protocol

Physico-chemical parameters: Physicochemical water quality parameters (Temperature, conductivity, pH and DO of the lake water were measured using a portable multimeter (Model HQ 40 d Multi Hach Lange) at different depths within the euphotic area, transparency (water clarity) was measured with Secchi disk (20 cm diameter). The turbidity of the lake water was measured using a portable digital turbidity meter (Model Oakton: T-100). Water samples were collected from Lake Hayq using plastic sampling bottles for chemical analysis (nutrients) based on standard procedures [13]. 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, nitrate-NO_3, and ammonium-NH_4^+) in Pre-rainy (April-June), Rainy (July-September), Post-rainy (October-December) and dry (January-March) seasons.

In the Laboratory, total alkalinity was determined from 100 ml of the unfiltered water sample taken from the surface by titration with 0.1N HCl with bromocresol green used as an endpoint indicator [14]. The major dissolved inorganic nutrients (soluble reactive phosphorus-SRP, total phosphorous-TP, dissolved silicate-SiO_2, nitrite-NO_2, and nitrate-NO_3, were determined using the standard method of APHA, 1995 (Table 2).

Nutrients	Method
SRP	Ascorbic Acid
TP	Unfiltered water digested using potassium–peroxodisulphate, and autoclaved at 120 0C 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

In addition to the above inorganic nutrients, Ammonium ion was analyzed in Addis Ababa University Geology department, Isotope Laboratory.

Data analysis

The collected data were analyzed using Multivariate Statistical analysis, Two-way ANOVA to see the difference in water quality parameter variations with seasons and sites through application SPSS (Version 16).

Results

Physicochemical water parameters

The multivariate analysis (Two-way ANOVA) showed that there was a significant difference in DO, temperature, Conductivity, Secchi disk depth and Chlorophyll-a ($P<0.05$) within seasons and sampling sites unlike turbidity, total alkalinity and pH ($P>0.05$) (Table 3). The least pH (7.7 ± 0.1) was recorded at Ankerkeha River during the rainy season and the highest pH (9 ± 0.01) was recorded at Pelagic during the post rainy season and littoral during the pre-rainy season. The least conductivity (848 ± 11.8 µS cm^{-1}) was recorded at Ankerkeha during post-rainy and the highest (952.5 ± 69.2 µS cm^{-1}) was recorded at Pelagic during the rainy season. The least Secchi disk depth (1.27 ± 0.4 m) was recorded at Littoral during the dry season and the highest (4.49 ± 1.5 m) was recorded at Pelagic during the Pre-rainy season. The least Chlorophyll-a (2.33 ± 0.7 µgL^{-1}) was recorded at Ankerkeha during Pre-rainy and highest (6.16 ± 0.8 µgL^{-1}) was recorded at Littoral during the rainy season. The least turbidity (1.9 ± 0.6 NTU) was recorded at Pelagic during the dry season and the highest (4.27 ± 0.7 NTU) was recorded at Ankerkeha during the rainy season. The least total alkalinity (8.63 ± 0.12 meqL^{-1}) and the highest total alkalinity (9.4 ± 0.17 meqL^{-1}) were recorded at Ankerkeha during dry and rainy seasons respectively (Table 3).

Depth profiles of temperature and dissolved oxygen

Water temperature and DO vary with depth and season in Lake Hayq. The maximum water temperature at the deepest depth (20 m) at the open-water site ranged from 22.6-23.8°C during the pre-rainy season and minimum values ranged from 21.4°C to 22.2°C during the dry season. In Lake Hayq, the temperature difference along the depth profile was very low (<1˚C) during all sampling seasons. In Lake Hayq, except for the 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 the pre-rainy season and to a maximum of 7.47 mg L^{-1} inrainy season at the open water site. The minimum dissolved oxygen (DO) recorded was 6.29 mg L^{-1} (91.5% saturation) during the pre-rainy season at 20-meter depth in the pelagic part of the lake.

Parameters	Sites	Seasons			
		Dry	Pre-Rainy	Rainy	Post-Rainy
		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 (˚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	1.73 ± 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
Chlorophyll-a (µgL^{-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 (meqL^{-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 3: Physicochemical parameters (means and Standard deviation, SD) measured at three sampling sites (Ankerkeha, Pelagic, and Littoral).

Inorganic nutrients

The major inorganic nutrients analyzed in the present study were nitrogen (nitrite-NO_2, nitrate-NO_3-N, NH_3), phosphorus (Soluble Reactive Phosphorus-SRP and Total Phosphorus-TP), and dissolved silicate (SiO_2). The concentrations of each of the measured nutrients are found in Table 4. There was a significant variation in inorganic nutrient concentration among sampling sites in four seasons (Dry, Pre-rainy, Rainy and Post-rainy) ($P<0.05$).

The least NO_2 (52.2 ± 5.43 µgL^{-1}) was recorded at Pelagic site during Rainy season and the highest NO_2 (138.6 ± 11.5 µgL^{-1}) was recorded at Ankerkeha during the post-rainy season. The least NO_3 (147.1 ± 1.3 µgL^{-1}) was recorded at Littoral and Pelagic sites during Pre-rainy season and the highest NO3 (181.8 ± 0.0 µgL^{-1}) was recorded at

Ankerkeha during the dry season. The least NH_3 (13.3 ± 3.7 μgL^{-1}) was recorded at Pelagic site during the dry season and the highest NH_3 (79.3 ± 1.0 μgL^{-1}) was recorded at Ankerkeha during Pre-rainy season. The least SiO_2 (55.3 ± 2.5 μgL^{-1}) was recorded at the Littoral site during the Post-rainy season and the highest SiO_2 (203.1 ± 0.2) was recorded at Ankerkeha during the dry season. The least SRP (0.5 ± 0.0 μgL^{-1}) was recorded at Littoral and Pelagic sites during the rainy season and the highest SRP (12.3 ± 3.0) was recorded at Ankerkeha during the dry season. The least TP (0.9 ± 0.01 μgL^{-1}) was recorded at Pelagic during Rainy season and the highest TP (80.2 ± 1.5 μgL^{-1}) was recorded at Ankerkeha during Pre-rainy season.

Parameters	Sites	Seasons			
		Dry	Pre-Rainy	Rainy	Post-Rainy
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
NO_2 (μgL^{-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 ± 5.43	90.6 ± 7.7
NO_3 (μgL^{-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 ± 1.3
	Pelagic	172.7 ± 1.3	164.9 ± 0.0	159.6 ± 1.3	147.1 ± 0.0
NH_3 (μgL^{-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 ± 0.0	24.6 ± 0.0
SiO_2 (μgL^{-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 (μgL^{-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 (μgL^{-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

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

Discussion

Physicochemical water quality parameters

Lake Hayq is a highland lake with a mean depth of 31 m and 81 m maximum depth. Though, the lake is located in the highland (about 1900 m), the average surface water and deeper layer water temperature varied between 23°C and 20°C, respectively, which are higher than most highland lakes in Ethiopia. For instance, lower surface and deeper layer water temperatures of 16.7°C and 14.9°C, respectively were recorded for highland lakes of Dendi and Wonchi [15]. Vijverberg et al. [16] have measured the mean surface temperature of around 18.5°C and 20°C for Lake Hashenge and Tana. The unusual higher temperature in Lake Hayq might have been the result of volcanic activity [16]. 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 [17]. Total alkalinity concentrations for natural waters may range from 0 mg/L (very low) to more than 500 mg/L (very high) [18].

In the present study, the Secchi-disk depth value is 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 the dry season. Generally, the mean Secchi-disk depth values of Lake Hayq was 3.5 m giving euphotic depth of about 10m and mean chlorophyll-a value of 4.03 μgL^{-1}. The Secchi-disk depth value measured by different scholars in Lake Hayq was different at different times and they related the value 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 [19]. However, Elizabeth Kebede et al. [2] have reported a very low Secchi-disk depth value of 1.2 m and relatively high chlorophyll-a of 17 μgL^{-1}, which was associated with the change of trophic status from Oligotrophic to Eutrophic state. The trophic status change of Lake Hayq was also recently confirmed by Tadesse Fetahi et al. [17] that have reported mean Secchi disk depth (0.8-6.3 m) and Chlorophyll-a (12.9 mg m-3). The higher algal biomass and seasonal change and persistent occurrence of heavy taxa in Lake Hayq were influenced by atelomixis, partial mixing [17]. On the other hand, very low chlorophyll-a (<5 μgL^{-1}) and a higher Secchi-disk depth value of 5 meters were reported by Vijverberg et al. [16]. As indicated in Vijverberg et al. [16], the higher water temperature in a deeper layer might be due to geothermal activities in the bottom layerthat may contribute to vertical mixing seasonally and increase nutrients for excessive phytoplankton growth (eutrophication) temporarily. However, in the present study, the mean Secchi-disk depth (3.5 m), mean chlorophyll-a (4.03 μgL^{-1}) and CTSI value (40.13) showed that the lake is mesotrophic. The change in trophic status of Lake Hayq might be due to a reduction in total phosphorus and Chlorophyll-a are used in Carlson's Trophic State determination formula. Common carp invasion which has a grazing effect on phytoplankton as observed from gut content analysis of common carp and sedimentation of the Lake might have contributed for the reduced total phosphorus and Chlorophyll-a values [20].

Conclusion and Recommendations

In conclusion, the inorganic nutrient, especially nitrate was higher. The higher nitrate, total phosphorus, soluble reactive phosphorus, and silicon indicate the possibility of nutrient enrichment of Lake Hayq from runoff, solid and liquid wastes from nearby lodges, and siltation through Ankerkeha River. This nutrient enrichment of the lake shortly will bring eutrophication, water quality degradation. Therefore, integrated waste management and watershed management should be implemented through active participation of the local people.

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