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Variations in the Composition and Biomass of Phytoplankton Species as a Function of Physicochemical Factors in Lake Kuriftu, Central Ethiopia

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Abstract

Background: Analyzing the spatio-temporal dynamics of physicochemical and phytoplankton communities provide valuable insights into water quality, ecosystem health, pollution sources, and supports effective water resource management and conservation efforts.

Objective: The objective of this study was, therefore, to evaluate water quality status of Lake Kuriftu using a combination of both biotic and abiotic factors.

Materials and Methods: Water samples were collected from the Lake in triplicates both in the dry and wet seasons from five different sampling sites based on Lake zonation, and human interference during the wet and dry season in 2018. Physico-chemical parameters such as temperature, pH, dissolved oxygen and electrical conductivity of the water were measured *in situ* with a portable multimeter probe (HACH, HQ 40d, USA) designed for water samples, while turbidity was measured by a portal digital Turbidimeter (T-100 Singapore). Secchi depth (Z_{SD}) was estimated using a 20 cm diameter Secchi disk. Concentrations of nutrients and heavy metals were determined following standard methods. Abundance of phytoplankton and their seasonal dynamics were estimated in terms of biovolume and calculated using the appropriate geometric shape of the major species. The data were then analyzed with a multivariate analytic technique Redundancy Analysis (RDA) to illustrate the correlations between abundance of dominant phytoplankton species and physicochemical characteristics. Correlation between dominant phytoplankton specie and environmental variables were analyzed by the Bi-plot of the constrained Redundancy Analyses (RDA).

Results: The pH, TDS, DO and Turbidity were in the ranges of 8.55 ± 0.13–9.06 ± 0.02, 134 ± 1–137 ± 2 mg L^{-1}, 7.26–9.42 mg L^{-1} and 8.39–78.6 NTU, respectively. Cadmium and chromium concentrations were below the detectable level both in the dry and wet seasons while the concentration of lead was above the WHO permissible limits in the dry season. The concentration of iron was high in the dry season and low in most of the sites in the wet season. A total of six major phytoplankton groups were identified. These were Chlorophyceae, Cyanophyceae, Bacillariophyceae, Dinophyceae, Cryptophyceae and Euglenophyceae in order of their abundance and frequency of occurrence. The species richness varied among the sampling sites in the lake and a total of 30 species belonging to six families and 24 genera were recorded from the lake.

Conclusion: The water quality parameters such as, pH, TDS, DO, and Turbidity exhibited consistent ranges within acceptable limits. Cadmium and chromium concentrations remained undetectable throughout both the dry and wet seasons while the concentration of lead was above the WHO permissible limits in the dry season. Phytoplankton distribution showed a remarkable difference and Blue-green algae was the most dominant species. Thus, further research should be conducted to explore long-term phytoplankton trends and factors influencing Blue-green algae dominance.

Keywords: Chlorophyll-a; Nutrients; Phytoplankton; Water Quality Index

1. Introduction

Phytoplankton are tiny, microscopic plants that consist of photosynthetic pigments to play a crucial role as producers in aquatic ecosystems. Changes in the composition and abundance of these organisms can be identified by analyzing the Spatio-temporal dynamics of phytoplankton populations (Zębek, 2014; Ma *et al.*, 2022; Wilhelms *et al.*, 2022; Yaqoob *et al.*, 2023). This information can be used to assess the health of aquatic ecosystems. Phytoplankton community structure is very sensitive to changes in water quality. When too many nutrients are available, phytoplankton may grow out of control and form harmful algal blooms, which can produce extremely toxic compounds that can harm aquatic ecosystem. Spatio-temporal dynamics of physicochemical and phytoplankton analysis can be used for water quality monitoring and water resource management. Water resource managers can evaluate the

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impact of anthropogenic activities on lakes, reservoirs and rivers by analyzing the changes in water quality and phytoplankton populations over time (Gogoi *et al.*, 2019; Mishra *et al.*, 2019; Ma *et al.*, 2022; Wilhelms *et al.*, 2022; Yaqoob *et al.*, 2023).

Spatio-temporal water quality analysis can help to evaluate the impact of anthropogenic activities on lakes, reservoirs and rivers (Mishra *et al.*, 2019). Thus, spatio-temporal analysis of physicochemical and phytoplankton can be used to monitor aquatic resource over time. Monitoring spatio-temporal dynamics of physicochemical and phytoplankton analysis enables the early detection of water quality issues. Changes in phytoplankton populations can indicate shifts in nutrient availability, pollution levels, or other environmental stressors (Wilhelms *et al.*, 2022). Appropriate measures can be taken to mitigate potential problems and prevent further deterioration of water quality by identifying these changes.

Phytoplankton analysis can help to identify the sources of pollution in water bodies. Certain phytoplankton species are known to thrive in polluted conditions, and their presence can indicate the presence of contaminants (Ma *et al.*, 2022). This information can be used to target pollution sources and implement effective pollution control measures. Changes in phytoplankton populations can indicate imbalances in nutrient levels, eutrophication, or other ecological disturbances. Therefore, understanding these dynamics could help in developing appropriate management strategies, which can be implemented to maintain a healthy ecosystem.

Examining the spatio-temporal dynamics of physicochemical and phytoplankton communities will yield a comprehensive insight into water quality, facilitate early issue detection, pinpoint pollution sources, evaluate ecosystem health, and underpin data-driven decision-making. The objective of the research is, therefore, to contribute to the understanding of the spatio-temporal variations of phytoplankton biomass and species composition in Lake Kuriftu and their relationship with physicochemical factors. This knowledge can have implications for the management and conservation of Lake Kuriftu ecosystem.

2. Materials and Methods

2.1. Description of the Study Area

Lake Kuriftu (8°47' N and 39°00' E, Figure 1) is one of the crater lakes found in Bishoftu town in central Ethiopia at the distance of 47 kilometers from the capital Addis Ababa in the southeasterly direction and at an elevation of 1860 meters above sea level. It is a shallow man-made lake with a mean depth of six meters (Eshete Assefa and Seyoum Mengistou, 2011). It was once a dry crater depression that was later filled by diverting Belbela River, a tributary of the Mojo River, for irrigation purposes in the area (Seifu Kebede *et al.*, 2001). Many anthropogenic pressures on the lake have recently emerged, including irrigation, resort and hotel construction, and livestock watering which causes waste disposal to the lake.

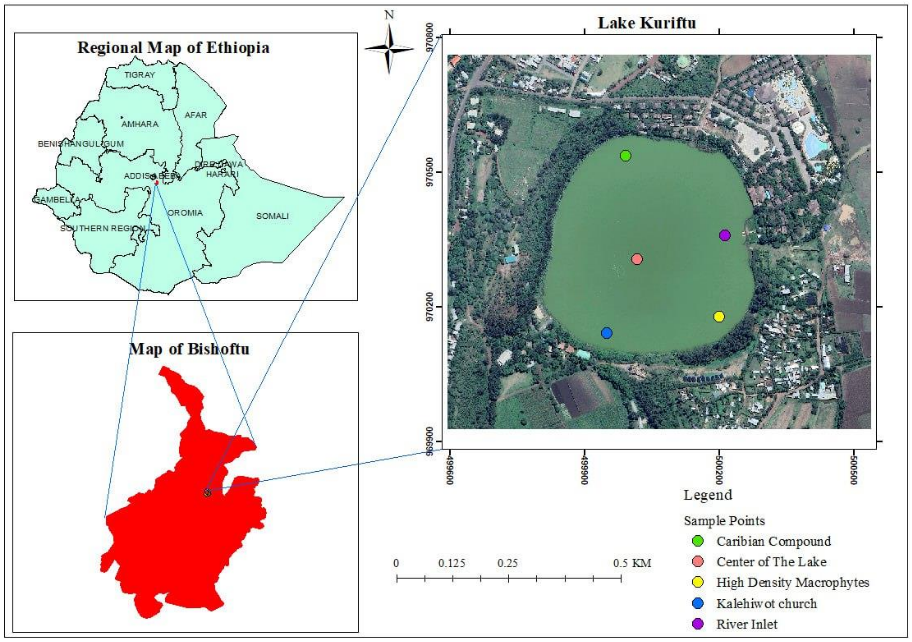

Figure1. Map of Lake Kuriftu with the location of sampling sites.

2.2. Study Design and Sample Collection

Since there was spatial heterogeneity in the level of anthropogenic pressure on Lake Kuriftu, representative sampling sites were selected during the preliminary study after being cognizant of wind direction, presence/absence and nature of point source pollutant. Five sampling sites were selected. These were the S1 (Run off inlet), S2 (high density Macrophytes), S3 (Kalehiwot church), S4 (Carbian compound) and S5 (Center of the lake or offshore) each with high spatial independence. An offshore sampling site was included to allow for comparisons between locations near the waste discharge points in the lake and those further away (offshore). During the study period, samples were collected in triplicates from each sampling station. Following established protocols, water samples were collected and transported (APHA, 1999) during the dry and wet season of 2018. Samples were collected in 1L polyethylene bottles for laboratory investigation of essential quality markers. The bottles were properly rinsed with distilled water after being treated with concentrated HNO_3.

2.3. Physico-chemical Parameters

In situ measurements of physico-chemical parameters such as electrical conductivity, total dissolved solids, pH, temperature, dissolved oxygen, and transparency were made using portable kits (Hanna model No. Hl98195). Other chemical characteristics, namely, alkalinity, hardness, nutrients and heavy metals were measured in the lab using APHA-approved procedures (1999). After filtering the lake water via glass fiber filters (GF/F) with a pore size of 43arameterrs such as inorganic nutrient content were examined. According to APHA, (1999) guidelines, soluble reactive phosphate-P (SRP), ammonia-N (NH_3 + NH_4^+-N), nitrite-N (NO_2-N) and molybdate-reactive silica (SiO_2) were analyzed according to APHA (1999). Total phosphorus (TP) was measured in unfiltered water samples. Titration with 0.1N HCl using a mixed end-point indicator (Bromocresol green-methyl red) was used to determine alkalinity, whereas titration with EDTA was used to determine hardness. The Azide Modification of the Winkler method (5210 B- 5 Day BOD) and standard protocols of the HACH kit DR/2400 procedure were used to measure BOD_5 and COD, respectively.

2.4. Sample Collection, Identification and Enumeration of Phytoplankton

Composite samples of phytoplankton were collected using an automatic horizontal van-dorm sampler which sampled phytoplankton from discrete depths throughout the euphotic zone and mixed in equal proportions. The samples were then preserved with Lugol's solution and transported to laboratory for further analysis. 1000 ml of samples were then allowed to stand for a duration equivalent to 6 hours per cm of sedimentation chamber under dark condition (Hötzel and Croome, 1999). The top 90% of the total sample volume was carefully siphoned off after sedimentation without disturbing the settled phytoplankton. The remainder was gently shaken before transferred to a 1 ml sub sample to the counting chamber and allowing it to settle for 30 seconds before counting (Hotzel and Croome, 1999). The phytoplankton samples were examined at different magnification levels under an inverted microscope and the encountered taxa were identified to genus and species level using various taxonomic literatures (Hecky and Kling, 1987; Hindák, 1992; Krammer *et al.*, 2002; Komárek and Komárková-Legnerová, 2003; František, 2006; Arguelles *et al.*, 2014; Lone, 2014). The abundance of each species was also determined using a Sedgewick-Rafter cell (Hotzel and Croome, 1999).

Chl-a analysis:

To estimate phytoplankton biomass, composite samples of appropriate volume (100-150 ml) of samples were filtered through GF/F for Chl-a analysis. After homogenization with a glass rod, pigments were extracted using 90% aqueous acetone for 24 hours in cold dark conditions. The pigment extracts were centrifuged for 5 minutes at 3000 rounds per minute. Using a UV-Vis spectrophotometer (JENWAY, 6405 UV/Vis Spectrophotometer), the absorbance of the extracts was measured at 665 and 750 nm before and after acidification with 0.1 ml of 1N HCl (applied to the extract in a 1cm cuvette). The concentration of Chl-a was computed using the formula as indicated in Talling and Driver (1963):

$$\mathrm{Chl-a}\left(\frac{\mathrm{mg}}{\mathrm{l}}\right) = \frac{11.4 \times \mathrm{K} \times ((665\mathrm{b} - 750\mathrm{b}) - (665\mathrm{a} - 750\mathrm{a}) \times \mathrm{Ve}}{\mathrm{Vf} \times \mathrm{Z}}$$

Where, 665b and 750b are absorbance at 665 nm and 750 nm before acidification, respectively; 665a and 750a are absorbance at 665 and 750 nm after acidification, respectively; Ve = Volume of extract in ml; Vf = Volume of sample filtered in liter; and Z = Path length of the cuvette.

2.5. Estimation of Trophic State Index (TSI)

To classify water bodies into different trophic states, the Trophic State Index was used. As a result, it evaluates water quality in terms of nutrient enrichment and its relationship to excessive algae or macrophyte growth (Bucci *et al.*, 2015). The methods used to calculate TSI for tropical waters (Lamparelli 2004) are adaptations of Carlson's Index, based on the concentrations of TP and Chl-a.

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

$$\mathrm{TSI\ (TP)} = 10 \times (6 - \frac{[1.77 - 0.42 \times \ln[\mathrm{TP}])}{\ln 2}$$

The TSI is the simple arithmetic average of the indices for Chl-a and TP:

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

Where, [Chl-*a*] is the chlorophyll *a* concentration in μgL^{-1}; [TP] is the total phosphorus concentration in μgL^{-1}; and ln is the natural logarithm.

2.6. Estimation of Water Quality Index (WQI)

The assessment of WQI, a figure ranging from 0–100, is another way to assess the water quality of a lake. Its calculation is based on the parameters EC, p^{H}, DO, NO$_3$-N, TP, SRP, and turbidity (Bucci *et al.*, 2015), each with a distinct weighting based on its relative importance in the index's calculation. The National Sanitation Foundation (USA) defined these factors as indicators of water quality in order to develop an index to classify water quality. According to the formula, the index was calculated using weighted multiplicand quality of water according to the parameters (Ramakrishnaiah *et al.*, 2009):

$$WQI = \prod_{i=1}^{9} qiwi$$

Where, WQI = Water Quality Index; qi = quality parameter obtained by the specific average quality curve; and wi = weight assigned to the parameter, based on its importance in quality between 0 and 1 values.

2.7. Phytoplankton Diversity Analysis (H')

To estimate species diversity and richness, the Shannon and Wiener (1949) index of species diversity was used. It's one of the most widely used approaches for determining species diversity and richness.

$$H' = -\sum_{i=1}^{s} (\mathrm{pilnpi})$$

Where, H' is the Shannon and Wiener diversity index and pi = the proportion of individuals or the abundance of species i the proportion of total cover in the sample.

Evenness or equitability is a measurement for comparing a specific species' unique representation to a hypothetical community in which all species are equally prevalent. The evenness index is a number that ranges from 0 to 1. The greater the value of the evenness index, the more evenly distributed the species are within a specific distribution area (Kent and Coker, 1992). Evenness index was calculated using the following formula:

$$J = \frac{\mathrm{H}}{\mathrm{In(S)}}$$

Where, J = evenness; H = Shannon-Wiener Diversity Index; and S = total number of species in the sample.

2.8. Statistical Data Analysis

Using CANOCO for Windows 4.5 version, a multivariate analytic technique Redundancy Analysis (RDA) was employed to illustrate the correlations between abundance of dominant phytoplankton species and physicochemical characteristics (Ter-Braak and Smilauer, 2002). Cluster Analysis (CA) was also utilized to categorize sampling sites in order to characterize their similarities/linkages and differences. Graphs were created using sigma plot and Microsoft Excel to present mean values between sampling sites.

3. Results and Discussion

3.2. Physical Characteristics of the Lake Water

The lake water transparency ranged between 0.39–0.46 meters in the dry season and 0.24–0.29 meter in the wet season, respectively. Turbidity is believed to be higher during the wet or rainy season which is mainly a result of run off and other activity. The variations of transparency with seasons might be due to changes in the amount of suspension of inorganic particles, phytoplankton biomass variation, and particulate materials loading through runoff during the wet season.

The transparency values were higher than the recorded values by Brook Lemma *et al.* (2001) for the same lake. This higher value of transparency may be due to low productivity and different sampling season of the same Lake. This was slightly lower than the Secchi-disc depth reported by Zelalem Dessalegn (2014) which was 0.37–0.60 m in the same lake. The vertical transparency of Lake Kuriftu was higher than that of Legedadi (0.082–0.11 m) (Adane Sirage, 2006) and Koka reservoirs (0.28 m) (Elizabeth Kebede and Willen, 1998) and Lakes Ziway (0.35 m) (Elizabeth Kebede *et al.*, 1994), and Chamo (0.21–0.375 m) (Eyasu Shumbulo, 2004). However, transparency was higher in Lake Kilole (ZSD = 0.37–1.8 m) (Brook Lemma, 1994) and Babogaya (ZSD = 1.48–4.46 m) (Yeshiemebet Major, 2006) than the transparency observed in this study. This may be due to the differences among the lakes in terms of plant cover in the catchment areas and human activities.

Dissolved oxygen in the wet season varied spatially between 7.26 to 9.42 mg L^{-1} in the surface of the lake. The highest dissolved oxygen was recorded in the open station. This was comparable with the dissolved oxygen level in Lakes Bishoftu (7.2 to 12.11 mg L^{-1}) and Ziway (8.72 to 10.7 mg L^{-1}) (Zinabu G. Mariam *et al.*, 2002). However, it was slightly lower than lake Chamo (10.26 to 17.61 mg L^{-1}) (Fenta Adane and Almaz Kidanemariam, 2016). Lake Chamo has better water mixing pattern compared to Lake Kuriftu, it may lead to higher overall dissolved oxygen levels. The DO value found in this study was within the WHO standard (5.0–14.6 mg L^{-1}) for healthy water (WHO, 2006). Dissolved oxygen value less than 5 or greater than 14.6 indicates the impairment of the quality of the water body.

The variation in pH was in the range from 8.44 ± 0.21–8.91 ± 0.01 in the dry season and in the range from 8.55 ± 0.13–9.06 ± 0.02 in the wet season. The water in the entire sampling site was found to be alkaline in both the dry and wet seasons. Among the sampling sites, the lowest pH was recorded at the center of the Lake. The results found in this study are comparable with results of previous study (8.2–8.8) in the same Lake (Zelalem Desalegn, 2007). The pH values were higher than the pH values reported from Lake Hawassa (Adimassu Woldesenbet, 2015), which ranges from 6.98–7.71 values. The pH values found in this study were slightly higher than the values reported by Brook Lemma *et al.* (2001) for the same lake.

In addition, the pH values were lower than the pH values of the crater lakes such as Lake Bishoftu 9.2 and Lake Babogaya 8.84–9.09 (Yeshiemebet Major, 2006). The pH in all the water samples was above the permissible limit (6.5–8.5) for agriculture, drinking and recreation (WHO, 2006). The high value of pH might be attributed to the high photosynthetic activity of the alga which consumes free CO_2 and results in the lowering of the hydrogen ion (H^+). The total dissolved solid in the water samples varied 134 ± 1–137 ± 2 mg L^{-1} in the dry season and 134 ± 1–136 ± 2 mg^{-1} in the wet season. The result found in this study was lower than the result reported for Lake Chamo (651–656 mg L^{-1}) and Lake Ziway (200–400 mg L^{-1}) (Fenta Adane and Almaz Kidanemariam, 2016).

The electrical conductivity in the water samples also varied from 268 ± 5 to 280 μScm^{-1} ± 3 μScm^{-1} in the dry and wet seasons. The electrical conductivity in Lake Chamo (720–782 μScm^{-1}) was higher (Fenta Adane and Almaz Kidanemariam, 2016), while the value in Fincha reservoir (78 μScm^{-1} – 101 μScm^{-1}) was lower than the results found in the present study (Yeshi Gergara *et al.*, 2015). The results in all the water samples are in agreement with the WHO standard for drinking water (1500µ Scm^{-1}) and EPA Standard (1000 μScm^{-1}). The observed electrical conductivity may be correlated with the existence of dissolved salts, including bicarbonate, calcium, sodium, magnesium, silica, sulfate, and various other ions present in the water. Turbidity varied from 7.86 NTU–19.56 NTU in the dry season and in the ranged from 8.39 NTU–17.28 NTU in the wet season. The lower turbidity value was recorded in the open station while the highest was recorded at the shore station (S1). The high turbidity at S1 might be due to the higher impact of silt and detritus loaded on to the runoff and high input of nutrients which enhance phytoplankton blooming.

The high turbidity at site S1, resulting from increased silt, detritus runoff, and nutrient input fostering phytoplankton blooming, is likely to adversely affect dissolved oxygen levels due to reduced light penetration, elevated organic matter decomposition, and potential oxygen depletion during algal decay. In addition, there was a significant variation in the turbidity of the water with the variation in the season, with lower values found for the wet season. However, the observed turbidity levels in this study align with those of Lake Chamo (7.10NTU–20.42NTU) (Fenta Adane and Almaz Kidanemariam, 2016) and that of Lake Hawassa (6.82 NTU and 20.98 NTU) (Adimassu Woldesenbet, 2015). However, it was lower than in Lake Tinishu Abaya (57 NTU–188NTU) (Yirga Enawugaw and Brook Lemma, 2018) and Lake Ziway (57 NTU–188NTU) (Girum Tamire and Seyoum Mengistu, 2013). The turbidity found in this study was higher than WHO standard limits. According to USEPA (2005), the recorded turbidity values, beyond 100 NTU, indicate very cloudy to muddy water conditions, potentially causing stress in certain fish species with prolonged exposure.

3.2 . Selected Heavy Metal Level

The concentrations of cadmium and chromium were below the detection limit in both the dry and wet seasons. The concentration of the two metals was below WHO (2006) permissible limit for drinking water. In contrast to the results of this study, Genawork Mola (2018) reported cadmium concentrations in the range of 0.096–0.17 mg L^{-1} for Lake Addele. The concentration of lead was in the range 0.0447 ± 0.002 to 0.056 ± 0.0001 mgL^{-1} in the dry season while it was below the detection limit (<0.00 mg L^{-1}) in the wet season. The result shows that the lead was higher during dry season. This might be due to the increasing of water level and this make the metals diluted and lower when we compared with the dry season. There is also a possibility that lead is often found in the air and dust blowing in the dry season may also deposit it in the water, thereby increasing its concentration. Thus, in most of the sampling sites, lead level in the dry seasons was slightly higher than the WHO standard values. Genawork Mola (2018) reported higher concentration of lead in the range of 1.4360 ± 0.001–2.84 ± 0.0001 mg L^{-1} for Lake Addele in Ethiopia. However, the concentration of iron ranged from 2.53 ± 0.08–11.84 ± 0.32 mg L^{-1} in the dry season and 0.055–5.47 mg L^{-1} in the wet season. The concentration in the wet season was significantly lower than that in the dry season ($P < 0.05$). However, the concentrations of iron in both seasons were higher than WHO standard (0.2 mg L^{-1}) for iron in drinking water in all the sites.

The elevated concentrations of iron in the water, surpassing the WHO standard of 0.2 mg L^{-1}, could indeed be linked to the substantial presence of dust in the Bishoftu area, particularly during the dry season, leading to its deposition into water bodies. Iron is naturally abundant in soil particles, and the prevalence of dust in the region may contribute to increased iron levels in the water. The interaction between airborne dust particles carrying iron and water bodies could facilitate the transfer of iron into the water, resulting in higher concentrations observed during both dry and wet seasons. This phenomenon underscores the complex interplay between environmental factors and water quality, highlighting the need for comprehensive monitoring and management strategies to mitigate the impacts of such contaminants on public health and ecosystems.

3.3 . Nutrients Concentration

The concentration of nitrate varied from 0.229–1.467 mg L^{-1} in the dry season with the average value of 1.1 ± 0.51mg L^{-1}, while the variation was from 146.322–165.852 μg L^{-1} in the wet season with the average value of 156.7 ± 8.39 μg L^{-1}. The concentration was significantly lower in the rainy season. This may be attributed to the effect of rainwater dilution. The average values found in dry season were higher than the average values reported from earlier investigation (Zelalem Dessalegn and Demeke Kifle, 2014). The concentrations in the present study are higher than the concentrations s reported from other lakes in the area such as Babogaya (1–31 μg L^{-1}) (Yeshiemebet Major, 2006), Lake Ziway (28-136.5μg L^{-1}) (Girma Tilahun and Ahlgren, 2010), and Bishoftu (25 μg L^{-1}) (Zinabu Gebre Mariam 1994). It was also higher than the values reported for Lake Hayq (Tadesse Fetahi, 2011), Hawassa (3.02 ± 0.86–8.87 ± 0.86) and Chamo (3.12–5.35 mg L^{-1}) (Girma Tilahun and Ahlgren, 2010). The high value of nitrate is probably because of nutrient enrichment of the lake from agricultural runoff and other anthropogenic sources in the catchment area. It might include both solid and wastewater from the catchment as well as the Kuriftu hotel and residential places around the Lake. In all the sample sites, the level of nitrate in the lake was within the permissible limit (10 mg L^{-1}) for drinking water WHO (2006). Nitrate concentration greater than 1 mg L^{-1} is considered as undesirable for aquatic life (Murdoch *et al.*, 2001). The amount of nitrate-nitrogen in unpolluted waters is usually less than 0.1mg L^{-1} (Chapman, 1996). Hence, the value recorded in the present study may indicate a considerable pollution of the Lake's water with the nutrient.

The level of ammonia in the sample sites varied from 22.424–93.08 μg L^{-1} in the dry season and from 14.384–34.162 μg L^{-1} in the wet season. The average concentration was 39.8 ± 30.1 and 25.2 ± 9.2 μg L^{-1} in the dry and wet seasons, respectively. There was a significant ($P < 0.05$) variation of ammonia concentration between the dry and wet seasons. The variation might be due to the dilution of the Lake's water with rain. The ammonium (NH_4^+) released into water bodies during the process of ammonification of organic nitrogen to ammonium. The two nitrogen species, unionized ammonia (NH_3) and ammonium (NH_4^+) exist in equilibrium in water and this is dependent on pH. High levels of ammonia can occur at the pH value of about 9.0. At this pH value, the ammonia occurs in forms toxic to fish (Fenta Adane and Almaz Kidanemariam, 2016). The NH_4-N becomes toxic to fish possibly because of one or more of the following cases: (1) impairment to the gill epithelium causing asphyxiation; (2) stimulation of glycolysis and suppression of Krebs cycle causing progressive acidosis and reduction in blood oxygen-carrying capacity; (3) uncoupling oxidative phosphorylation causing inhibition of ATP production and depletion of ATP; (4) disturbance of blood vessels and osmoregulatory activity disturbing the kidneys and liver; and (5) suppress the immune system and increase the susceptibility to parasitic and bacterial diseases (Augspurger *et al.,* 2003).

Moreover, ammonia can inhibit the process of nitrification by affecting both Nitrosomonas and Nitrobacter bacteria. This can also result in increased NH_4^+ accumulation in the aquatic environment and increased the toxicity to bacteria and aquatic animals (Camargo and Alonso, 2006). Ammonia concentration in the ranging between 0.05–0.35 mg L^{-1} NH_4-N mg L^{-1} might be toxic at short term exposure and in the range of 0.01–0.02 NH_4-N mg L^{-1} for long-term exposures (Camargo and Alonso, 2006).

The soluble reactive phosphorous (SRP) concentration ranged between 2.469–4.107 μg L^{-1} in the dry season and 0.473–0.883 μg^{-1} in the wet season. Most sites have showed similar concentrations in the wet season whereas sites 1 and 3 showed the lowest and highest concentrations, respectively. The SRP concentration also showed a significant variation between sampling seasons with higher concentration in the dry seasons. Similarly, Zelalem Desalegn (2007) reported higher concentration of SRP (8.64–51 μg L^{-1}) for the same lake in a dry season. The results found in this study were also lower than the results reported for Lake Addele (11.67–67 μg L^{-1}) (Zelalem Dessalegn, 2013), Bishoftu (280 μg^{-1}) (GebreMariam, 1994), and Chamo (26.4–91.7 μg^{-1}) (Eyasu Shumbulo, 2004). In addition, the mean SRP concentrations in this study were lower than Babogaya (0.04 ± 0.008mg^{-1}), Hora (0.17 ± 0.065 mg^{-1}) and Arenguadi (3.7 ± 0.49mg^{-1}) (Kibru Teshome, 2011). On the other hand, Yeshimebet Major (2006) reported closer results with this study from Lake Babogaya in contrast to the results of Kibru Teshome (2011). Phosphorus in water bodies is the major limiting nutrient for phytoplankton growth. Phosphate concentration starting from 0.01 mg L^{-1} will support algal species (Fenta Adane and Almaz Kidanemariam, 2016).

The level of total phosphorus (TP) ranged from 5.796–10.197 μgL^{-1} in the dry and from 5.540 – 9.327 μg L^{-1} in the wet season. This result is lower than the result reported for Lake Hawassa (0.28–51 mg L^{-1}) (Adimassu Woldesenbet, 2015). Grima Tilahun (2006) also found higher concentrations of total phosphorus for Lake Ziway (68.57 ± 14.6 μg L^{-1}), Hawassa (34.17 ± 13.2 μg L^{-1}) and Chamo (182 ± 60.5 μg L^{-1}). A total phosphorous concentration ranging between 0.43–0.55 mg L^{-1} was also reported for Lake Chamo (Fenta Adane and Almaz Kidanemariam, 2016). Also, the mean concentration of total phosphorus recorded in this study was lower than the level recorded for Lake Babogaya (0.13 ± 0.023mg L^{-1}), Hora (1.19 ± 0.25mg L^{-1}), and Lake Arenguadie (Hora Hadho) (13.25 ± 0.72 mg L^{-1}) (Kibru Teshome, 2011). Yeshi Gergara *et al.* (2015) also reported a higher total phosphorus content ranging between 1.3 mg L^{-1}–7.3 mg L^{-1}) for Fincha Reservoir. This suggests variable nutrient dynamics and potential anthropogenic influences in different water bodies.

3.4 . Algal Biomass as Chlorophyll-a

The concentration of chlorophyll-a was found to show a spatial and temporal variation during the study period (Figure 2). The value ranged from 12.47–45.7 mg L^{-1} in the dry season while the variation was 4.15–20.78 mg L^{-1} in the wet season.

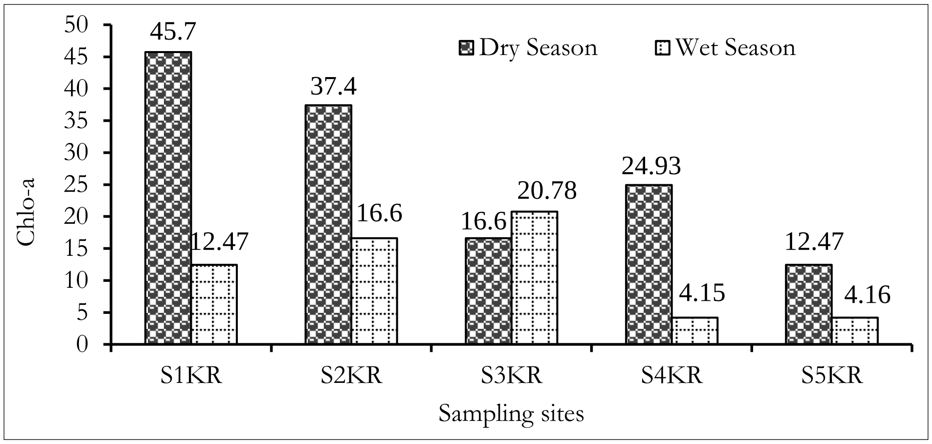

Figure 2. Chlorophyll-a concentration among the sampling sites during the period of 2018 for Lake Kuriftu.

The dry season had a significantly ($P < 0.05$) greater level of Chl-a than the wet season. This could be due to particle matters resulting from high runoff, which reduces light penetration depth. In the dry season, site 1 had the highest phytoplankton biomass, followed by site 2, and in the wet season, site 3 had the highest phytoplankton biomass. In the dry season, the lowest concentrations were found at sampling site 3 (16.6 g L^{-1}) and site 5 (12.47 g L^{-1}); in the rainy season, the lowest concentrations were found at sampling sites 4 and 5. The average chlorophyll-a concentration in Kuriftu Lake was 19.53 g L^{-1}, indicating that the lake was fully eutrophic. Water bodies having a chlorophyll-a content of 12.00-19.99g L^{-1} is classed as fully eutrophic (KDHE, 2011). The results from the dry season were comparable to those from research for the same lake by Zelalem Desalegn (2007) and Fincha reservoir (Yeshi Gergara *et al.*, 2015). The average chlorophyll-a value was lower than Lake Tinishu Abaya (Yirga Enawugaw and Brook Lemma, 2018), Lake Adale (Zelalem Dessalegn, 2013), and Lake Hawassa (Demeke Admasu, 2015). On the other hand, the results from Babogaya (Yeshiemebet Major, 2006) and Koka Reservoir (Elizabeth Kebede and Willén, 1998) were higher than results of the present study.

3.5 . Species Composition and Abundance of Phytoplankton

A total of 30 phytoplankton species were found grouped into six major phytoplankton classes (Table 1), which includes Bacillariophyceae, Chlorophyceae, Cryptophyceae, Cyanophyceae, Dinophyceae, and Euglenophyceae.

Table 1. Phytoplankton species identified in Lake Kuriftu during the period of 2018.

S/N	Phytoplankton species	Occurrence and abundance (individua ml^{-1})										Total	
		Kr_{S1}		Kr_{S2}		Kr_{S3}		Kr_{S4}		Kr_{S5}			
1	Chlorophyceae/Geen algae	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1.1	*Chlamydomonas reticula*	50	1050		1450				400		2450	50	5350
1.2	*Monariphidium contortum*				2350	50	450					50	2800
1.3	*Oocystis* sp.				650		1450		1750				3850
1.4	*Pediastrum duplex*	150	1050	550	400	350	950	450	50		550	1500	3000
1.5	*Pediastrum simplex*	550	1650	350	2300	1100		600	850	250	50	2850	4850
1.6	*Scenedesmus dimorphus*						150						150
1.7	*Scenedesmus armatus*		50										50
1.8	*Scenedesmus linearis*		200			100			50	50		150	250
1.9	*Scenedesmus quadricauda*			50	450						50	50	500
2	Cyanophyceae/Cyanobacteria/Cyanoprokayrota/Blue green algae												
2.1	*Anabaena circinalis*	5500	3150	6500	9800	13550	14700	10750	13950	7450	6950	43750	48550
2.2	*Cylindrospermopsis africana*	5950	10550	8300	10550	5650	11900	5550	10900	6600	10350	32050	54250
2.3	*Merismopedia punctata*		950		2100		600				1150		4800
2.4	*Microcystis aeruginosa*	12100	15850	13900	17050	14550	20650	12550	13800	12050	12650	65150	80000
2.5	*Microcystis ichthyoblabe*	350		600		2750	1550	2150	950	850		6700	2500
2.6	*Planktolyngbya tallingii*	1250	8650	650		1550	6350	2800		1150	9800	7400	24800
2.7	*Pseudoanabaena* sp.	3850	8450	5050	9050	6250	10150	7700	5450	6400		29250	33100
2.8	*Raphidiopsis curvata*	650	6450	350	10500	750	7300	950	4650	600	3550	3300	32450
3	Bacillariophyceae/Diatoms												
3.1	*Aulacoseira granulate*	350	600	450	150	700	50	200	400	350	50	2050	1250
3.2	*Cyclotella* sp.			800		1350	350	600		1100	800	3850	1150
3.3	*Cymbella aspera*	150	700	550	50	200	50		700	350	100	1250	1600
3.4	*Gyrosigma atenuatum*		700		250		50				50		1050
3.5	*Navicula* sp.	250	550		50	150	50		150		50	400	850
3.6	*Nitzschia* sp.	300	50			50	200		50		50	350	350
3.7	*Surirella tenera*		650				1100		450		650		2850
3.8	*Thalassiosira fluviatile*	650		250	50	300	50	150	50	150		1500	150
4	Dinophyceae/Dianoflagelates												
4.1	*Peridinium cinctum*	350	1150	100	700	850		400	50	250	450	1950	2350
5	Cryptophyceae/Cryptomonads												
5.1	*Cryptomonas obovate*	200	1850	300	650	350		550	850	1200	1800	2600	5150
5.2	*Cryptomonas marssoni*		3350	650	19000	1050	2050	850	1350	950		3500	25750
6	Euglenophyceae/Euglenoids												
6.1	*Phacus longicauda*		2800		1850	50	2150		850		50	50	7700
6.2	*Lepocincilis ovum*						2550			1050	700	1050	3250

Note: *Kr = Kuriftu; KrS1 = Run off inlet; Kr S2 = High density phragmates; KrS3 = Right side of the Kalehiwot church; KrS4 = Carbian compound; and KrS5 = Center of the lake.*

Phytoplankton diversity in the present was higher than the diversity in Lake Adele (21 species; Zelalem Dessalegn, 2013) and lower than Babogaya (32 species) (Yeshiemebet Major, 2006), Ziway (67 species) and Chamo (44 species) (Elizabeth Kebede and Willén, 1998). The three phytoplankton groups including the green algae, blue green algae, and diatoms were the major components that represent the largest number of species (> 90%) and abundance. The dianoflagelates, cryptomonads and euglenoids accounted for less than 10% of the total phytoplankton richness represented by low numbers of species. The Shannon diversity index and species evenness value was in the range of 2.26–2.484 and 0.4039 to 0.4998, respectively (Table 2). The Shannon diversity index indicated that the highest diversity was recorded for the sampling site S1 and the lowest was recorded for the site S4. Moreover, the value of evenness in S1 site was also greater in all the other sites. In addition, the high (0.8797) Simpson diversity index (1-D) revealed the highest species diversity occurred at site S1 compared to all the sites. On the other hand, the lowest Simpson diversity index (1-D) was recorded for site S4. This shows that species diversity was lowest in this site.

Table 2. Phytoplankton species diversity, evenness and richness in Lake Kuriftu.

Site	S1	S2	S3	S4	S5
Species richness (S)	24	24	27	23	26
Individual	56400	69775	72425	55875	53325
Simpson (1-D)	0.8797	0.8787	0.8652	0.8518	0.8713
Shannon weaver diversity index (H')	2.484	2.416	2.389	2.26	2.369
Species Evenness (H'/ln(S))	0.4998	0.4665	0.4039	0.4168	0.4109

The most prevalent taxonomic group was blue-green algae, which contributed 84% and 80% of the abundance in the dry and wet seasons, respectively. With eight species, it was also the second in species richness. Green algae were the first diverse taxonomic group with nine species. Diatoms like as blue-green algae, were the second most diverse taxonomic group, with eight species reported. In addition, Girum Tamire and Seyoum Mengistou (2013) identified 20 species in six phytoplankton groups. Green algae had the largest diversity, followed by Blue green algae and Diatoms. Similar species richness order of diversity was reported by Zelalem Dessalegn and Demeke Kifle (2013). However, the overall number of species reported by these authors was 25, which was fewer than the finding of the current study. In the Ethiopian Rift Valley lakes such as Lakes Awasa, Chamo, and Ziway, blue-green algae and green algae accounted for the majority of phytoplankton species (Grima Tilahun and Ahlgren, 2010). In most temperate and tropical lakes, these two types of algae represent the most diversified taxonomic group (Agusti *et al*., 1990).

During the beginning of the dry season and rainy months, most phytoplankton taxa had a stronger dominance. This could be due to the availability of plant nutrients and rising turbidity in the water. Blue-green algae flourish in turbid and mixed water columns with high nutrient levels primarily phosphate due to their physiological and structural adaptations for buoyancy regulation. *Microcystis aeruginosa* and *Cylindrospermopsis africana* were the most abundant and widely distributed Blue-green algae species in both wet and dry seasons. They contributed more than 58 and 28% abundance in the dry season and 28% and 19% in the wet season, respectively. This finding is in line with the results of the previous research in the lake (Zelalem Dessalegn and Demeke Kifle, 2013). For Fincha Reservoir, Yeshi Gergara *et al.* (2015) reported similar results. In other crater lakes such as Lake Bishoftu and other Rift Valley lakes such as Lake Awassa, Chamo, and Ziway in Ethiopia, the dominance of Microcystis aeruginosa was detected during mixing and rainy period rather than the time of temperature stability (Tadesse Fetahi, 2014).

3.6 . Trophic State of the Lake

The TP-TSI was in the range of 45.11–48.53 and 44.8–47.99 in the dry and wet seasons, respecively (Figure 3). Similarly, the Chla-TSI ratio ranged from 59.1–65.48 and 53.71–61.61 in the dry and wet seasons, respectively. The trophic state (TSI) of Lake Kuriftu varied from 52.44 to 55.69 in the dry and 49.3 to 54.8 in wet seasons with the average value of 54.37 ± 1.28 and 51.63±2.32, respectively, Lake Kuriftu in Eutrophic stage. As phosphorus is a limiting nutrient in algal growth, total phosphorus is commonly measured in the assessment of trophic state. Algal concentration can be estimated indirectly by determining the Chl-a. The more chlorophyll, the more phytoplanktons and more eutrophic state of the lake.

According to Kumar and Hosmani (2010), Chl-a measurement can be applied as a primary index for trophic state classification and inferring lake functioning. Although eutrophication is a natural process, it is often exacerbated over time by human activities, which is known as cultural eutrophication according to Steffanson *et al.* (2001). Humans have an impact on lake ecosystems by raising plant nutrient concentrations, particularly phosphorus. Agricultural runoff, sewage or waste water, and livestock ranching all can contribute nutrients to lakes. This results in excess of nutrients in water bodies, resulting in algal blooms. The decomposition of dead algal biomass may cause a reduction in dissolved oxygen in lakes, resulting in an anoxic environment.

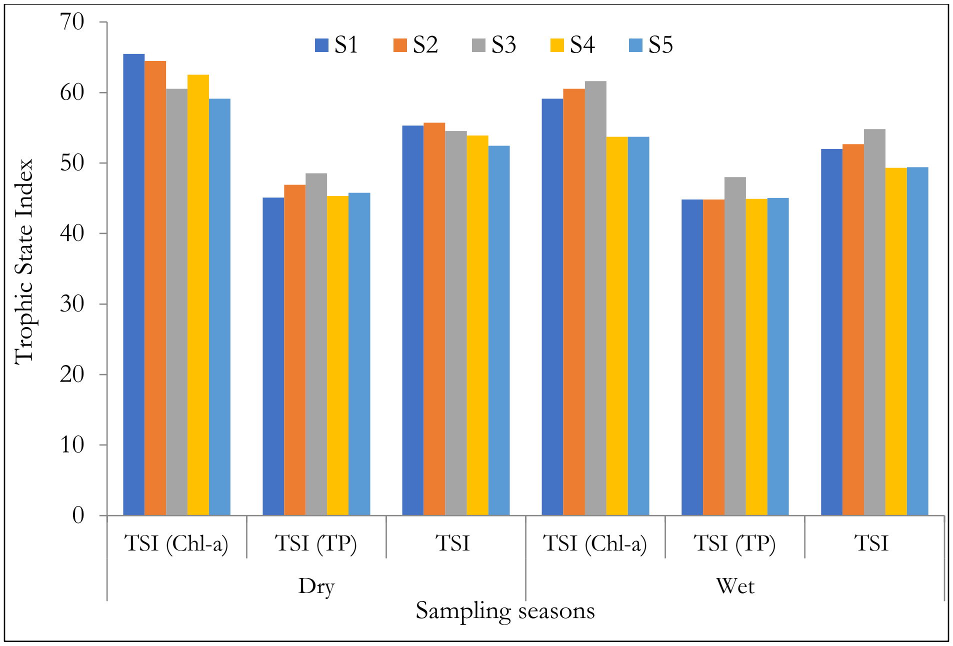

Figure 3. Trophic state index for Lake Kuriftu.

3.7 . Cluster Analysis (CA)

The dendrogram of sampling sites obtained using Ward's approach is shown in Figure 4. Three sets of five sampling sites were developed. Cluster 1 corresponded to site S2, which lies in the Lake's southern area. The lake rim is covered in phragmates and other trees in this area. Sites S1 and S5, which are located in the eastern and central portions of the Lake, respectively, are included in Cluster 2. Runoff water from nearby farm regions is a source of contaminants at this location. Domestic sewage and agricultural runoff could be pollution sources, particularly dispersed and unsettled wastewaters from local communities and agrochemicals from agricultural runoff. Cluster 3 included sites S3 in the western section of the lake and S4 in the northern part. In terms of physical and chemical variables, the CA revealed that each location had unique characteristics.

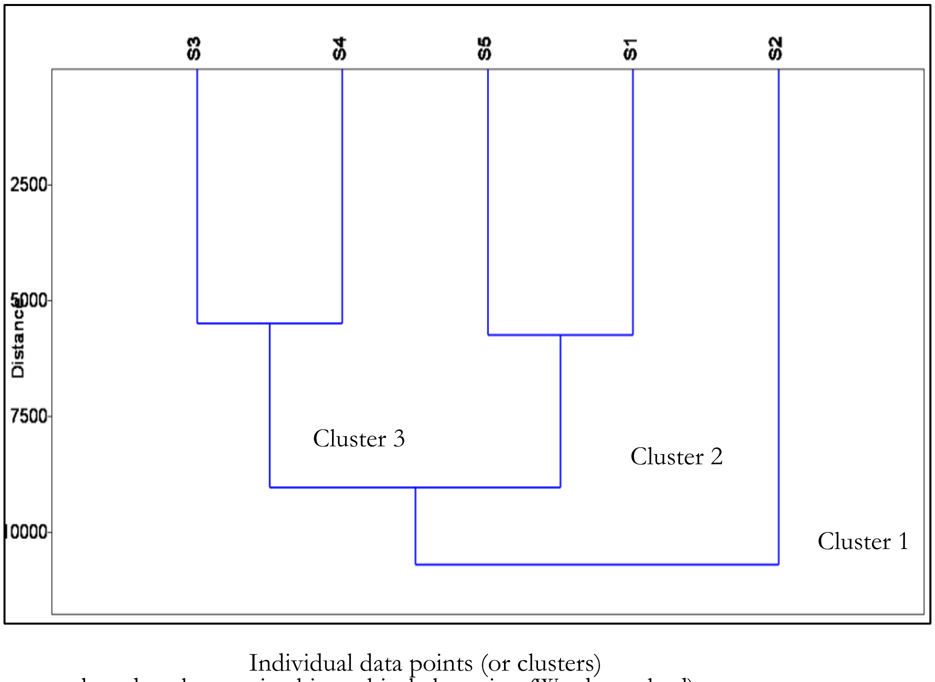

Figure 4. Dendrogram based agglomerative hierarchical clustering (Wards method).

3.8. Relation of Phytoplankton Assemblages of Environment Variables

A constrained Redundancy Analyses (RDA) was used to determine the correlations between the major phytoplankton species and environmental conditions that govern phytoplankton species diversity and abundance in Lake Kuriftu, and the graph is illustrated in Figure 5. The RDA graph's first two axes explained 89.4% variation in the species-environment relation. The first axis explains 49.2% of the variation and was positively correlated with DO and total alkalinity (Table 3). The correlations with pH, electrical conductivity, and total dissolved solids were likewise positive but only had modest relationships. Ammonia, turbidity, iron, total phosphorous, and reactive phosphate were all found to be negatively correlated. The second axis was positively connected with nitrate, silica, and total alkalinity, while pH, total dissolved solids, soluble reactive phosphate, total phosphate, and turbidity were negatively correlated. The occurrence of dominant phytoplankton species, *Chlamydomonas reticula* and *Cryptomonas obovata*, were positively correlated with silica, dissolved oxygen, and total alkalinity, but negatively correlated with nitrate. *Phacus longicauda, Cryptomonas marssoni, Raphidiopsis curvata*, and *Pediastrum simplex*, on the other hand, had a high positive correlation with silica, dissolved oxygen, and total alkalinity and negatively correlated with electrical conductivity, total dissolved, and pH of the water.

Table 3. Summary of the statistics of RDA diagram.

Axes	1	2	3	4
Eigenvalues	0.492	0.402	0.078	0.028
Species-environment correlations	1	1	1	1
Cumulative percentage variance of species data	49.2	89.4	97.2	100
Species-environment relation	49.2	89.4	97.2	100
Sum of all eigenvalues	1			
Sum of all canonical eigenvalues	1			

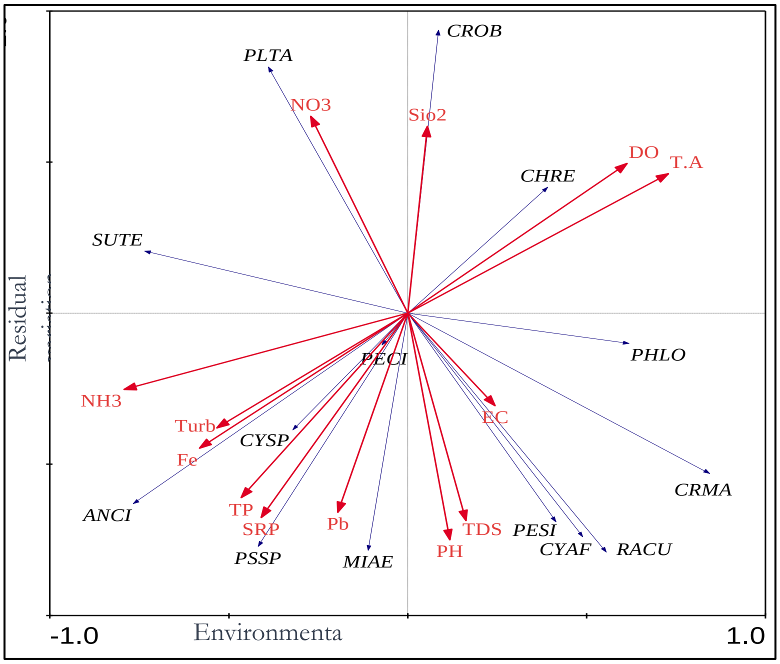

Figure 5. Bi-plot of the constrained Redundancy Analyses (RDA, CANOCO for Windows 4) for dominant phytoplankton specie (black arrows) and environmental variables (red arrows).

CHRE = Chlamydomonas reticula; PESI = Pediastrum simplex; ANCI = Anabaena circinalis; CYAF = Cylindrospermopsis Africana; MIAE = Microcystis aeruginosa; PLTA = Planktolyngbya tallingii; PSSP = Pseudoanabaena sp.; *RACU = Raphidiopsis curvata; CYSP = Cyclotella* sp.; and *SUTE = Surirella tenera.*

3.9 . Water quality index

The overall water quality was estimated to be 213.81, which was within the range of 200 to 300 WQI, indicating that Lake Kuriftu exhibits poor water quality. This could be owing to the high nutrient content, which is primarily comprised of nitrate and total phosphate. The pH and turbidity levels were also high, contributing to poor quality of the water. The phytoplankton biomass and suspended particle matter may be responsible for the high turbidity value.

4 . Conclusion

The results of this study have demonstrated differences in the values of the different physicochemical parameters, including concentrations of nutrients and selected heavy metals in Lake Kuriftu. The concentrations of most physicochemical characteristics were lower during the rainy season than during the dry season which is attributed mainly to dilution effect of the lake water. Lake Kuriftu is classified as a fresh water lake based on its total dissolved solids and electrical conductivity measurements. The study uncovered those concentrations of cadmium and chromium remained below detectable levels throughout both dry and wet seasons, adhering to WHO guidelines for potable water. Nonetheless, lead concentrations exhibited a notable increase during the dry season, likely attributable to elevated water levels and deposition from atmospheric sources, albeit exceeding WHO thresholds marginally.

The phytoplankton community is characterized by low species diversity and cyanobacteria dominance, with Microcystis spp. as the dominant species. The dominance of Cyanobacteria indicates eutrophic conditions and poor lake biological health. Thus, further research should be conducted to explore long-term phytoplankton trends, assess factors influencing Blue-green algae dominance, and investigate ecological implications for sustained water quality management.

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