Assessment of the Relationship Between Physico-Chemical Parameters and Phytoplankton Biomass Based on Principal Component Analysis (PCA) and Pearson Correlation Coefficient: A Case of Lake Naivasha, Kenya

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Abstract

Physico-chemical parameters play a significant role in determining the limnological and ecological functioning of aquatic spaces. These parameters have the ability to sustain aquatic functions and values as well as support organisms. The study was conducted to determine the relationship between physico-chemical parameters and phytoplankton biomass. Water samples for nutrient and algae biomass were collected in triplicates monthly at seven sampling points in Lake Naivasha and laboratory analyses were conducted following the standard methods described by the American Public Health Association (APHA). Data was organized and analyzed with Single Factor Analysis of Variances (ANOVA). Correlation and PCA was done using Microsoft Excel 2010 and Minitab software and the significant differences considered at p-value ≤ 0.05. Tukey pairwise multiple comparisons were used for post hoc analysis. The results showed the mean temperature of 22.73 ± 1.6 °C, DO 8.51 ± 0.87 mg/L, conductivity 233.85 ± 26.94 µS/cm, pH 8.13 ± 0.3. TN were 471 ± 170.61 µg/L, PO_4 5.88 ± 2.12 µg/L, TP 97.97 ± 49.06 µg/L, NO_3-N 6.70 ± 3.55 µg/L, NH_4-N 18.93 ± 10.91 µg/L and SiO_2 3.18 ± 2.99 mg/l. A total of one hundred and twenty-four (124) species belonging to six (6) taxonomic groups were identified. The family Chlorophyceae contributed to 43.84 % of the total phytoplankton biovolume. This was followed by the family Bacillariophyceae with 37.50 % and Cyanophyceae with 8.06 % of the total phytoplankton biovolume. The families Dinophyceae, Euglenophyceae, and Zygnematophyceae recorded lower phytoplankton biovolume of 5.79 %, 2.90 % and 1.91 %, respectively. Pearson correlation showed a positive showed a positive relationship between phytoplankton biomass and key physico-chemical parameter. The results indicate that Lake Naivasha is polluted with pollutants from domestic wastewater, agricultural and/ or surface run off. Sewage discharge point and R. Malewa mouth were identified as the main point sources of pollution. Therefore, there is need for measures to be put in place to reduce water pollution from these points in order to improve the water quality of the lake.

Keywords: Physico-Chemical Parameters, Phytoplankton, Biomass, Principal Component Analysis, Pearson Correlation Coefficient and Lake Naivasha

Introduction

Lake Naivasha is a tropical freshwater lake of much ecological and conservation importance being a Ramsar site (Anderson et al., 2008; Owino et al., 2020). Over the past few decades, the lake has undergone massive changes with respect to its limnological characteristics due to the many anthropogenic activities taking place around it (Njiru et al., 2014). These activities have resulted in the lake's pollution through discharge of agricultural effluents, partially treated urban sewage, and uncontrolled water abstraction for irrigated horticultural farms. These anthropogenic activities have influenced physico-chemical variables on the phytoplankton growth (Mugo, 2010; Omondi et al., 2022). The inflow of effluents in turn has made the lake become eutrophic. Lack of conservation measures and climate change impact has compounded the effects of these human activities in the lake (Mwamburi, Owili & Werimo, 2007). The negative consequences of these activities on the biological conditions in freshwater ecosystems are becoming increasingly pronounced with respect to the ecology of the lake. Increasing nutrients load has led to the proliferations of aquatic biota (Hubble & Harper, 2002a). Since 1963, the lake area has experienced several complex ecological changes and environmental challenges. These changes have been through land use transformation in terms of urban development, agricultural activities, and human settlements (Hubble & Harper, 2010). These changes have resulted in increased dependence on the depleted resources provided by the lake catchment leading to unsustainable use of lake water and its resources. All these changes lead to environmental perturbations like invasion of the lake by alien flora and fauna species, degradation of the lake catchment leading to increased siltation of the lake and hydrological changes due to water abstraction and climate change (Ballot et al., 2009). Environmental changes have led to transformation of the lake from clear water with a higher macrophytes biomass to a eutrophic state that is characterized by a high nutrient concentration and phytoplankton biomass (Kitaka, 1991; Hubble & Harper, 2010; Ndungu, 2014).

Phytoplankton are microscopic and single-celled organisms that are found freely floating in the water column (Omondi et al., 2022). They require light for photosynthetic activities, and this makes them tend to stay near the water surface. They are categorized according to their sizes; Picoplankton (<2 µm), Ultraplankton (2-10 µm), Nanoplankton (10-20 µm) and Microplankton (20-200 µm), such as diatoms and dinoflagellates (Chin, 2015). Phytoplankton are the major primary producers that generate organic biomass in large water bodies. They are very sensitive to changes in the environment because of natural and anthropogenic changes and for this; they therefore act as water pollution indicators and can be used in water quality monitoring (Sitoki, 2010). Their rapid reproduction may sometimes cause blooms that are a nuisance to the aquatic life. When these algal blooms die and decompose, they lower the content of dissolved oxygen in the water through uptakeof this gas by the microbes decomposing the dead algal biomass (Sitoki et al., 2012). Phytoplankton being the main source of energy, their diversity, and abundance in the aquatic system is of significance in the food chain as they provide energy to the higher trophic levels. The fishery potential of any aquatic ecosystem is therefore dependent on the measurement of phytoplankton primary productivity (Zare, 2015, Mosoti et al., 2024). Various algal species undergo changes in their spatial and temporal distribution because of changes in the physico-chemical variables of the environment at different times and places (Omondi et al., 2020). Phytoplankton uses carbon dioxide from the atmosphere during photosynthesis thus acting as carbon sinks through carbon sequestration. This therefore leads to a decrease in the effect of global temperature increase. Photosynthesis also produces oxygen as a by-product, which in turn aerates the water systems (Reynolds, 2006; Rayori et al., 2021). Phytoplankton affects the pH of water when they use up carbon dioxide during primary productivity, this results in the rise of pH by increasing the hydroxide levels. Alternatively, during respiration, there is more oxygen intake and more carbon dioxide production when there are blooms, this lowers the water pH due to the reduced hydroxide levels (Omondi et al., 2020). They are therefore a major concern for water quality and the ecosystem health as they act as indicators of the deteriorating status of aquatic ecosystem. Increase in atmospheric temperatures has been shown to have a positive impact on some phytoplankton species of cyanobacteria that tend to proliferate because of favourable temperature (Lewis, 1978; Omweno et al., 2021; Omweno et al., 2024). Cyanobacteria can also fix atmospheric nitrogen and have ability to move up and down in water columns (to capture light) hence have got a greater advantage over other phytoplankton taxa making them to depict higher biomass in tropical lakes (Sitoki, 2010; Sitoki et al., 2012). Therefore, the main objective of this paper was to assess the relationship between physico-chemical parameters and phytoplankton biomass based on Principal Component Analysis and Pearson Correlation Coefficient in L. Naivasha.

Materials and Methods

Study Area and Sampling Sites

Lake Naivasha is located on the floor of Africa's Eastern Rift Valley at an altitude of 1895 m above sea level and lies within an area of approximately 153.2 km^2 during the wet season. It is the second-largest freshwater lake in Kenya after the portion of Lake Victoria within the Kenyan side. It is located at latitude 00 45' S and longitude 36^0 20' E. Lake Naivasha geographical location is mainly distinguished by Kinangop Plateau and Eburru Hills as it lies between these physical features. The main components of the lake are Lake Sonachi, Lake Oloiden and the main lake itself. Seven pre-defined sampling points were identified (Figure 1). The seven sampling stations were selected to provide representative coverage of the different components and geographical areas of Lake Naivasha, including the main lake, Lake Oloiden, and Lake Sonachi. This ensured that samples captured spatial variations in environmental conditions across the lake system, improving the reliability of the study findings.

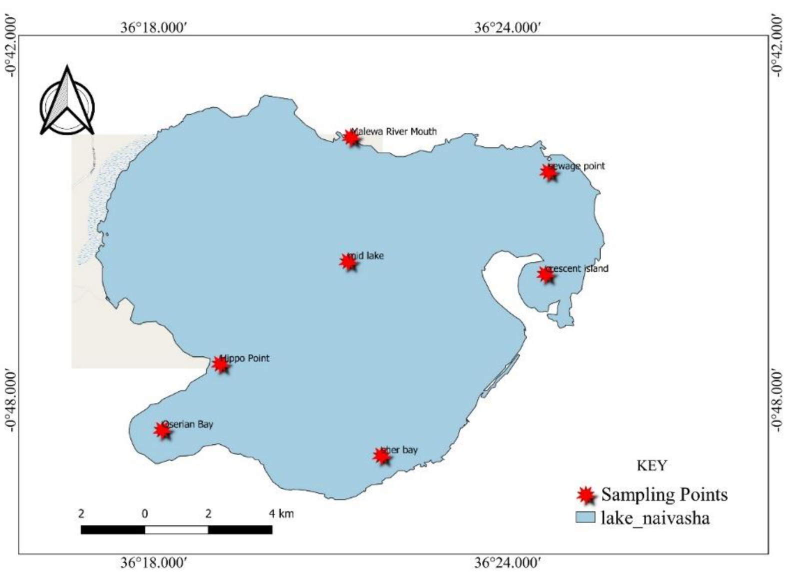

Figure 1: Naivasha map showing sampling sites

Sampling, Data Collection and Analysis

Physico-Chemical Parameters

In each station, triplicate measurements were recorded for physico-chemical variables. Three water samples were taken in 500 ml acid washed bottles for nutrients analysis. Sampling was done monthly for six months at each site from February 2019 to July 2019. The samples were taken at the surface. Acid washed bottles were used for samples collection in triplicates. The collected samples were immediately filtered using GFC filters with pore size 0.45µm and the filtrate used to determine the dissolved nutrients (Ammonium, nitrates, SRP and silicates). After collection, the samples were kept in a cool box at 4^0C and transported to KMFRI Kisumu laboratory where further analysis was done. Temperature, DO, pH, TDS, salinity, and conductivity were read *in situ* using multimeter water quality parameter model YSI professional with meters for the respective parameters. Ammonia content was analyzed using phenol hypochlorite method while nitrates and nitrites were analyzed using the Cadmium-reduction method. Total nitrogen and total phosphorous were determined on unfiltered water samples. Digestion of TN with potassium per sulfate and autoclaving process was carried out to convert organic nitrogen to nitrate nitrogen while TP was oxidized using hot 5% potassium per sulfate in distilled water, autoclaved then further cooled at room temperature to liberate organic phosphorus as inorganic phosphate. Soluble reactive phosphorous (PO4-P) was analyzed using the Ascorbic acid method. Silicates were analyzed using the heteropoli blue technique according APHA (1998). Spectrophotometric measurements of the samples were taken using a standard UV-visible atomic absorbance spectrophotometer (AAS) model Z-2000.

Determination of Phytoplankton Biomass as Biovolume (mm^3/L)

Water samples for the determination of phytoplankton community structures were collected by use of plankton net of 20 microns at the water surface (10 cm depth). The net was then rinsed using deionized water in order to wash off the remaining algal cells attached to the net. The plankton net content was then poured into a well-labelled pre-rinsed acid washed algal bottles at each station. The samples were then preserved by adding 2-3 drops of 1% Lugol's solution. The samples were stored at 8 ^{0}C cooler box for laboratory analysis. At the laboratory, each station sample was done according to the procedure by Sitoki (2010). Quantitative analysis of the phytoplankton cells and enumeration was done by use of Sedgewick-Rafter counting chamber. Enumeration of the algal cells was done using the Zeiss Axioinvert 35 inverted microscope model at 100X and 400X magnification. The identifications were made up to the genus level and where possible to species level.

For each taxon, the cell length, width and depth were measured from a minimum of 20 randomly selected specimens. Biovolume was calculated using geometric approximations (Rott, 1981; Wetzel & Likens, 2000). *Microcystis* colonies were measured at 40X magnification. The density of the cells per unit of the projection area of the colony was estimated to be using a higher magnification (400X). The depth of each colony was estimated by focusing on the top and bottom of the colony using the fine adjustment of the microscope. The following taxonomic literatures were used for the identification of Cyanobacteria: Komarek & Anagnostidis (1998), Komarek et al. (2002), Komarek & Anagnostidis (2005). The eukaryotic algae taxonomic literature included Huber-Pestalozzi (1942) and Krammer & Bertalot- Lange (1988, 1991) for diatoms, Komarek & Fott (1983) for Chlorococcales and Huber-Pestalozzi (1950) for Cryptophyta and

Dinophyta, and Talling (1987) for Zygnematophyceae (Sitoki, 2010). Biovolume calculation was determined as shown in the formula below according to Rott (1981) and Wetzel & Likens (2000):

Biovolume (mm^3/L) = Geometric shape x Factor x Number of counts …………..Equation 1

Where Factor refers to the dimensions of the counting chamber and the microscope at X400

Data Analysis

Data was organized, described using Microsoft Excel 2010 software and loaded into Minitab where further analyses were performed using with Single Factor Analysis of Variances (ANOVA), PCA, and Pearson correlation coefficient. Significant differences among the sampling sites were considered at a predetermined p-value of ≤ 0.05. Turkeys pairwise multiple comparisons were used as post hoc to determine which sampling sites significantly differed and clarify the actual source of significant differences. Descriptive statistics were used to trends of different parameters.

Results

Physico-Chemical Parameters

Crescent Island recorded the highest mean secchi depth of 84.46 cm ± 18.56 SD, this was followed by Hippo Point with 61.95 cm ± 19.14 SD, and Oserian Bay recording 60.04 cm ± 14.95 SD. Sewage Discharge Point and the Mouth of R. Malewa recorded low mean secchi depth of 35.75 cm ± 10.73 SD and 35.84 cm ± 12.10 SD respectively. Single factor ANOVA test revealed that the lake secchi depth showed significant differences among the sampling stations ($F_{(6, 35)} = 8.0923$, $p = 0.001$). *Post hoc* Tukey Pairwise Comparisons revealed that mean secchi depth at Crescent Island (84.46) differed significantly from Mid-lake point (56.58), Sher Bay (50.58), and Sewage Discharge Point (35.75). Sewage Discharge Point, Mouth of R. Malewa, and Hippo Point showed higher mean temperature values of 24.24^0C ± 2.03 SD, 23.60^0C ± 2.02 SD and 23.01^0C ± 1.59 SD. Sher Bay and Crescent Island recorded low mean temperature values of 22.41^0C ± 2.24 SD and 21.75^0C ± 0.89 SD respectively. Single factor ANOVA showed that there was no significant difference in temperature among the sampling points ($F_{(6, 35)} = 0.6022$, $p = 0.7266$). Sewage Discharge point and Hippo Point had the highest levels of mean dissolved oxygen values of 8.88 mg/L ± 1.33 SD, 8.66 mg/L ± 2.16 SD and 8.78 mg/L ± 0.98 SD. Crescent Island had the lowest mean DO value of 7.84 mg/L ± 0.87 SD. Single factor ANOVA showed that there was no significant differences in dissolved oxygen between the sampling stations ($F_{(6, 35)} = 0.4858$, $p = 0.8143$). The mean conductivity values ranged from 228.42-244.33 $mScm^{-1}$ with Sewage Discharge Point and Mouth of R. Malewa recording higher mean values of 244.33 $mScm^{-1}$ ± 17.70 SD and 235 $mScm^{-1}$ ± 24.90 SD respectively. The mean conductivity value was lowest at the Mid-lake station (228.42 $mScm^{-1}$ ± 31.78 SD). Single factor ANOVA showed that there was no significant difference in mean conductivity levels between the sampling stations ($F_{(6, 35)} = 0.1915$, $p = 0.9772$). The mean pH values ranged from 7.90-8.22 with Sewage Discharge Point having the highest value of 8.22 ± 0.40 SD and Crescent Island recording the lowest mean pH value of 7.90 ± 0.40 SD. Single factor ANOVA showed that there was no significant difference between pH in the sampling stations ($F_{(6, 35)} = 0.5953$, $p = 0.7319$) (Table 1).

Table 1: Spatial variation in the physico-chemical parameters (Mean ± SD)

Stations	Temperature (°C)	DO (mgL^{-1})	pH	Conductivity (μScm^{-1})	Secchi depth (cm)
Sewage Discharge point	23.24 ± 2.04	8.66 ± 2.19	8.22 ± 0.40	244.33 ± 17.70	35.75 ± 10.7
River Malewa mouth	23.60 ± 2.02	8.11 ± 1.43	8.04 ± 0.39	235.00 ± 24.90	35.83 ± 12.1
Hippo Point	23.01 ± 1.59	8.78 ± 0.98	8.19 ± 0.32	231.42 ± 21.15	61.95 ± 19.1
Oserian Bay	22.67 ± 2.02	8.63 ± 1.14	8.20 ± 0.35	230.83 ± 26.69	60.04 ± 15
Sher Bay	22.44 ± 2.24	8.88 ± 1.33	8.21 ± 0.30	232.33 ± 31.68	50.58 ± 14.7
Mid-lake Point	22.45 ± 2.32	8.70 ± 0.71	8.12 ± 0.46	228.42 ± 31.78	56.58 ± 7.7
Crescent Island	21.75 ± 0.89	7.84 ± 0.87	7.90 ± 0.40	234.58 ± 41.12	84.46 ± 18.6
F-Value	0.6022	0.4858	0.5953	0.1915	8.0923
p-value	0.7266	0.8143	0.7319	0.9772	0.00002*

Nutrients

Sewage Discharge Point and Mouth of R. Malewa recorded higher mean SRP value of 9.99 µg/L ± 12.66 SD and 8.11 µg/L ± 2.51 SD respectively. Crescent Island had the lowest mean SRP value of 4.11 µg/L ± 1.78 SD (Table 2). Single factor ANOVA test revealed that SRP showed no significant differences between the sampling stations ($F_{(6, 35)} = 0.9675$, p = 0.4614). Sewage Discharge Point and Mouth of R. Malewa recorder higher mean TP value of 167.65 µg/L ± 74.14 SD and 120.23 µg/L ± 64.63 SD respectively. Oserian Bay had the lowest mean TP value of 69.44 µg/L ± 36.56 SD. Single factor ANOVA test revealed that there were significant differences between the mean TP levels among the sampling stations ($F_{(6, 35)} = 2.5059$, p = 0.04). *Post hoc* Tukey Pairwise Comparisons revealed that the mean total phosphorous at Sewage Discharge Point (167.6) differed significantly from the mean total phosphorous at the Mouth of R. Malewa (120.2) and Oserian Bay (69.4). Sewage Discharge Point, Sher Bay, and Mouth of R. Malewa recorded higher mean TN values of 584.15 µg/L ± 227.18 SD, 514.89 µg/L ± 234.78 SD and 489.19 µg/L ± 209.92 SD respectively. Hippo Point had the lowest mean TN value of 399.18 µg/L ± 206.45 SD. Single factor ANOVA test revealed that there was no significant difference in the mean TN levels among the sampling stations ($F_{(6, 35)} = 0.6251$, p = 0.7089). Sewage Discharge Point and Mouth R. Malewa recorded higher mean nitrate nitrogen levels of 11.04 µg/L ± 9.89 SD and 13.66 µg/L ± 14.27 SD respectively. Hippo Point and Mid-lake stations recorded the lower mean values of 3.73 µg/L ± 2.57 SD and 3.77 µg/L ± 2.23 SD respectively. Single factor ANOVA test revealed that there was no significant difference in the mean nitrate nitrogen levels among the sampling stations ($F_{(6, 35)} = 1.9894$, p = 0.0937). Sewage Discharge Point had the highest ammonium nitrogen mean value of 46.18 µg/L ± 69.27 SD and Sher Bay had the lowest ammonium nitrogen mean value of 6.49 µg/L ± 4.11 SD. Single factor ANOVA test revealed that there was no significant difference in the mean nitrate nitrogen levels among the sampling stations ($F_{(6, 35)} = 0.9630$, p = 0.4642). Sewage Discharge Point and Sher bay had the higher mean silicate values of 3.79 mg/L ± 3.74 SD and 3.52 mg/L ± 3.63 SD respectively. Oserian Bay and Mid-lake had the lower silicates mean values of 2.47 mg/L ± 1.59 SD and 2.87 mg/L ± 3.03 SD respectively. Single factor ANOVA test revealed that there was no significant difference in the mean silicate levels among the sampling stations ($F_{(6, 35)} = 0.1230$, p = 0.9928) (Table 2).

Table 2: Spatial Variation in the Nutrient Concentration of L. Naivasha (Mean ± SD)

Station	SRP (µg/L)	TP (µg/L)	TN (µg/L)	Nitrates (µg/L)	Ammonium (µg/L)	Silicates (mg/L)
Sewage Discharge point	9.99 ± 12.66	167.65 ± 74.19	584.15 ± 227.18	11.04 ± 9.89	46.18 ± 69.27	3.79 ± 3.74
River Malewa mouth	8.11 ± 2.51	120.23 ± 64.63	489.19 ± 209.92	13.66 ± 14.27	17.13 ± 14.30	3.24 ± 2.75
Hippo Point	4.53 ± 2.90	85.98 ± 61.73	399.18 ± 206.45	3.73 ± 2.57	12.15 ± 10.83	2.95 ± 3.20
Oserian Bay	5.38 ± 5.84	69.44 ± 36.56	417.33 ± 145.27	4.25 ± 2.83	18.75 ± 27.82	2.47 ± 1.59
Sher Bay	4.67 ± 2.11	76.43 ± 38.22	514.89 ± 234.78	5.05 ± 2.79	6.49 ± 4.11	3.52 ± 3.63
Mid-lake Point	4.39 ± 2.36	82.32 ± 42.18	473.40 ± 166.96	3.77 ± 2.23	12.35 ± 11.99	2.87 ± 3.03
Crescent Island	4.11 ± 1.78	83.73 ± 45.81	424.96 ± 199.97	5.36 ± 2.56	19.50 ± 33.81	3.42 ± 3.30
F-value	0.9675	2.5058	0.6251	1.9894	0.9630	0.1230
p-value	0.4614	0.0404*	0.7089	0.0937	0.4642	0.9928

Phytoplankton Community Structure

A total of one hundred and twenty-four (124) species belonging to six (6) taxonomic groups were identified from Lake Naivasha (Table 3). The family Chlorophyceae was represented by 43 species consisting of 34.68 % by species composition, followed by the family Bacillariophyceae, which was represented by 38 species consisting of 30.65 % by species composition. The family Cyanophyceae that was represented by 24 species leading to 19.35 % species composition. Other taxonomic families included Zygnematophyceae, Euglenophyceae, and Dinophyceae represented by 9 (7.26%), 7 (5.65%) and 3 (2.42%) species respectively (Table 4). The most copious phytoplankton species recorded at the seven sampling stations belonged to the genera *Aulacoseira*, *Pediastrum, Monoraphidium*, *Scenedesmus,* and *Chroococcus*. *Euglena acus, Euglena virids*, *Phacus longicauda,* and *Trachelemonous* spp mainly dominated Sewage Discharge Point.

Table 3: Phytoplankton Species of Lake Naivasha

Chlorophyceae	Bacillariophyceae	Cyanophyceae
Ankistrodesmus fusiformis	*Achnanthes* sp.	*Anabaena flos-aquae*
Ankistrodesmus falcatus	*Amphora* sp.	*Anabaena limnetica*
Ankistrodesmus sp.	*Amphora ovalis*	*Anabaena spiroides*
Botryococcus braunii	*Aulacoseira ambigua*	*Anabaenopsis circularis*
Chlamydomonas ovalis	*Aulacoseira nyassensis*	*Aphanocapsa pulchra*
Chlorella vulgaris	*Aulacoseira schroidera*	*Aphanocapsa rivularis*
Chlorella sp.	*Aulacoseira ulna*	*Aphanothece* sp.
Coelastrum reticulatum	*Cyclotella kutzinghiana*	*Chroococcus limnetica*
Coelastrum microporum	*Cyclotella ocellata*	*Chroococcus* sp.
Crucigenia rectangularis	*Cymbella cistula*	*Chroococcus turgidus*

Crucigenia quadrata *Cymbella solea* *Coelomoron* sp.
Crucigenia sp. *Cymbella* sp. *Coelomoron vestitus*
Crucigenia tetrapedia *Diatoma elongatum* *Cylindrospermopsis africana*
Kirchineriella contrata *Diatoma hiemiale* *Lyngbya* sp.
Kirchineriella lunaris *Diatomella hustedtii* *Merismopedia convoluta*
Kirchineriella obesa *Fragillaria capucina* *Microcystis aeruginosa*
Monoraphidium sp. *Gomphonema acuminatum* *Microcystis wasenbergii*
Oocystis nageri *Gomphonema* sp. *Oscillatoria tenuis*
Oocystis borgei *Navicula granatum* *Plankolyngbya tallingii*
Oocystis lucastris *Navicula mutica* *Planktolygbya limnetica*
Oocystis parva *Navicula scutelloides* *Planktolyngbya circumcreta*
Oocystis pusilla *Navicula* sp. *Planktolyngbya contrata*
Oocystis solitaria *Nitzschia sub-acicularis* *Planktolyngbya* sp.
Pediastrum boryanum *Nitzschia dissipata* *Spirulina subsalsa*
Pediastrum duplex *Nitzschia lucastris*
Pediastrum simplex *Nitzschia palea* **Zygnematophyceae**
Pediastrum tetras *Nitzschia recta* *Closterium leibleinii*
Scenedesmus acuminatus *Nitzschia* sp. *Closterium navicular*
Scenedesmus bijugatus *Pinnularia major* *Cosmarium depressum*
Scenedesmus crassus *Pinnularia viridis* *Cosmarium cunningtonii*
Scenedesmus curvatus *Stephanodiscus astrea* *Cosmarium retusiforme*
Scenedesmus longus *Stephanodiscus* sp. *Cosmarium* sp.
Scenedesmus maximus *Surirella linearis* *Staurastrum paradoxum*
Scenedesmus obliquus *Surirella ovalis* *Staurastrum lunatum*
Scenedesmus quadrata *Surirella* sp. *Staurastrum* sp.
Scenedesmus sp. *Synedra acus* **Euglenophyceae**
Scenedesmus tenuispina *Synedra nyassae* *Euglena acus*
Schroederia Africana *Synedra ulna* *Euglena viridis*
Schroederia setigera *Phacus longicauda*
Tetraedron arthrodesmisforme **Dinophyceae** *Phacus pleuronectes*
Tetraedron inflatum *Ceratium branchycerous* *Phacus* sp.
Tetraedron minimum *Ceratium hirundinella* *Trachelemonous armata*
Tetraedron triangulare *Glenodinium pernardii* *Trachelemonous volvocina*

Table 4: Total Number of phytoplankton species and species composition in L. Naivasha

Taxonomic groups	Total no. of species	Species Composition (%)
Chlorophyceae	43	34.68
Bacillariophyceae	38	30.65
Cyanophyceae	24	19.35
Zygnematophyceae	9	7.26
Euglenophyceae	7	5.65
Dinophyceae	3	2.42
Total	124	100.00

The family Chlorophyceae contributed to 43.84 % of the total phytoplankton biovolume. This was followed by the family Bacillariophyceae with 37.50 % and Cyanophyceae with 8.06 % of the total phytoplankton biovolume. The families Dinophyceae, Euglenophyceae, and Zygnematophyceae recorded lower phytoplankton biovolume of 5.79 %, 2.90% and 1.91 % respectively (Table 5). Spatially, the total phytoplankton biovolume by composition was highest at Oserian Bay with 22.57 % followed by Hippo point with 20.27 %, then Mid-lake station with 22.00 %. Sher Bay with 3.56 %, recorded the lowest total phytoplankton biovolume (Table 6).

Table 3: Phytoplankton Biovolume in mm3 per Litre in Lake Naivasha

Taxonomic groups	No. of species	Phytoplankton Biovolume (mm^3/L)	Percentage Biovolume (%)
Chlorophyceae	43	623.4064	43.84
Cyanophyceae	24	114.5456	8.06
Bacillariophyceae	38	533.1642	37.50
Dinophyceae	3	82.3575	5.79
Euglenophyceae	7	41.2129	2.90
Zygnematophyceae	9	27.2176	1.91
Total	124	1421.90	100

Table 4: Spatial variation of Phytoplankton Biovolume in mm3 per Litre in Lake Naivasha

Sampling stations	No. of species	Phytoplankton Biovolume (mm3/L)	Percentage Biovolume (%)
Crescent Island	68	152.067	10.69
Hippo Point	72	288.164	20.27
Mouth of R. Malewa	59	144.706	10.18
Mid-lake	56	312.833	22.00
Oserian Bay	66	320.904	22.57
Sewage Discharge Point	55	152.608	10.73
Sher Bay	58	50.623	3.56

Chlorophyceae biomass was mainly contributed by *Monoraphidium* sp, *Pediastrum* spp, *Scenedesmus* spp, *Botyococcus braunii, Tetraedron* spp, and *Oocystis* spp. Bacillariophyceae biomass was majorly contributed by *Aulacoseira* spp, *Amphora* spp, *Navicula* spp, *Nitzschia* spp and *Synedra* spp. *Anabaena* spp, *Chroococcus* spp, *Aphanocapsa* spp, and *Microcystis* spp contributed highly to Cyanophyceae biomass. *Cosmarium* spp, *Closterium* spp, and *Staurastrum* spp contributed highly to Zygnematophyceae biomass while *Ceratium* spp dominated Dinophyceae biomass. *Euglena* spp, *Phacus longicauda,* and *Trachelemonous* spp dominated the Euglenophyceae biomass. This study showed that the total phytoplankton biovolume depicted variation within the sampling stations. Cyanophyceae except at Hippo Point and Mouth of R. Malewa that was dominated by Bacillariophyceae dominated Sewage Discharge Point, Mid-lake, and Oserian Bay. Bacillariophyceae recorded lower total phytoplankton biovolume at Sher Bay. High proportions of Chlorophyceae were recorded at Oserian Bay, Mid-lake and Crescent Island but was lowest at Sher Bay. The family Euglenophyceae recorded the highest total phytoplankton biovolume at Sewage Discharge Point while other stations recorded low abundances. Zygnematophyceae recorded the highest phytoplankton biovolume at Hippo point. The family Dinophyceae recorded higher biomass at Oserian Bay (Figure 2).

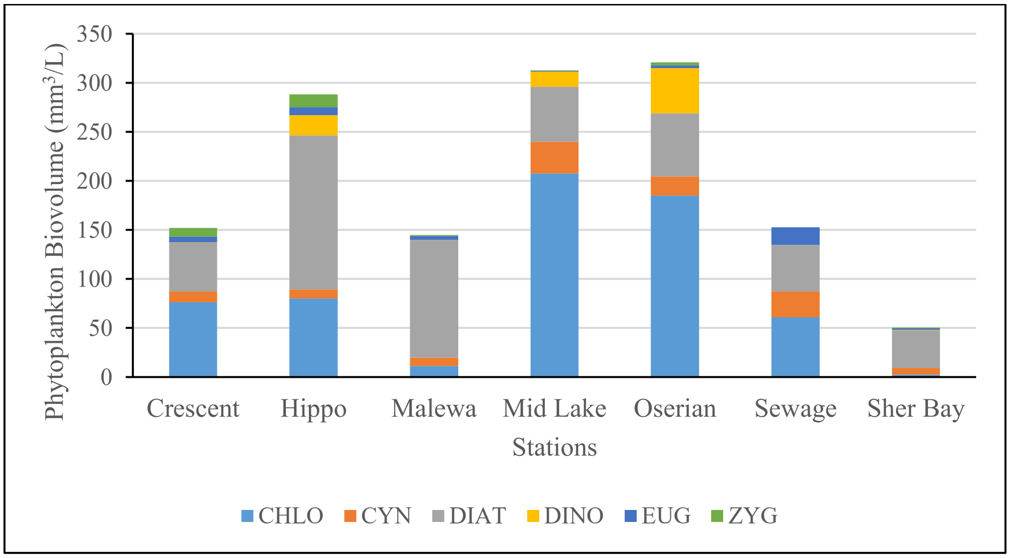

Figure 2: Spatial variation in phytoplankton biovolume of L. Naivasha

Principal Component Analysis (PCA)

Based on the Principal Component Analysis (Bi plot), Oserian Bay was highly associated by pH, dissolved oxygen, temperature, SRP and Dinophyceae. Sher Bay and Crescent Island were characterised by silicates, secchi and conductivity. Mid-lake and Sewage Discharge Point were associated with lake depth, ammonium nitrogen, Chlorophyll *a*, Total Nitrogen, Total Phosphorous, Cyanophyceae, Chlorophyceae and Euglenophyceae. Nitrate nitrogen, Bacillariophyceae and Zynematophyceae were associated with Hippo station and Mouth of R. Malewa (Figure 3).

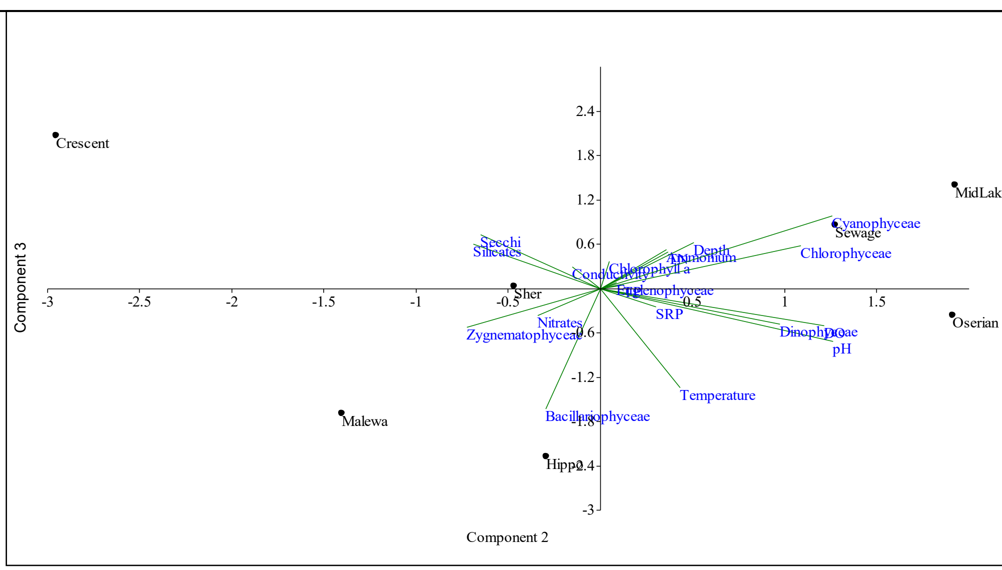

Figure 3: Principal Component Analysis (PCA) between water quality parameters and phytoplankton taxonomic groups

Euglenophyceae showed a strong positive correlation to TN (r = 0.48; p = 0.04), TP (r = 0.83; p = 0.015), SRP (r = 0.69; p = 0.010), ammonium (r = 0.88; p = 0.17) and conductivity (r = 0.89; p = 0.16) while Bacillariophyceae showed a positive strong correlation to temperature (r = 0.55; p = 0.012). Chlorophyceae showed a strong positive correlation to lake depth (r = 0.86; p = 0.181); Zygnematophyceae showed a strong positive correlation to secchi (r = 0.67; p = 0.32) while Dinophyceae had a positive correlation to DO (r = 0.34; p = 0.00), lake depth (r = 0.53; p = 0.012) and pH (r = 0.36; p = 0.039). Cyanophyceae showed a positive correlation to lake depth (r = 0.46; p = 0.039), ammonium (r = 0.45; p = 0.016), TN (r = 0.31; p = 0.012) and TP (r = 0.26; p = 0.181) (Table 7)

Table 5: Pearson Correlation Coefficient (r) for phytoplankton families-water quality parameter relationship (* shows significant relationship) at 95 % confidence interval

	Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae	Dinophyceae	Zygnematophyceae
SRP	-0.3467	0.2145	-0.0024	0.6980*	-0.3169	-0.5048
TN	-0.3889	0.3113*	-0.4683	0.4800*	-0.5875	-0.7555
TP	-0.3702	0.2682*	-0.0183	0.8315*	-0.5029	-0.3582
Ammonia	-0.0473	0.4570*	-0.2404	0.8884*	-0.1919	-0.2544
Silicates	-0.7248	-0.1495	-0.3343	0.5679*	-0.8950	-0.2164
Temp	-0.2861	-0.0079	0.5519*	0.3673	-0.0301	-0.2629
pH	0.0829	0.2311	0.0239	0.2121	0.3636*	-0.2618
Cond	-0.4788	0.0977	-0.1950	0.8889*	-0.5102	-0.2462
Nitrates	-0.5581	-0.0917	0.1170	0.4289	-0.5282	-0.4554
DO	0.1921	0.2662	-0.0165	0.0131	0.3419*	-0.1811
Depth	0.8626*	0.4632*	-0.0405	-0.4215	0.5380*	0.3370
Secchi	0.3295	-0.1593	-0.0952	-0.2950	0.2261	0.6765*

Discussion

Dissolved oxygen, temperature, pH, conductivity, and nutrients are some of the key water quality parameters for the survival of aquatic fauna and flora. Most importantly, nutrients are required for growth and production by plants and other aquatic organisms generally occur in the earth's crust in phosphorus to nitrogen ratio of 1:16 (Owino et al., 2022; Rayori et al., 2023). The higher secchi disk depth recorded at Crescent Island (84.46 cm) and Hippo Point (61.95 cm) was attributed to greater lake depth at these stations with minimal disturbances, less suspended particulate matter thus low turbidity. The low secchi disk depth recorded at Sewage Discharge Point (35.75 cm) and Mouth of R. Malewa (35.84 cm) was associated with increased sediment load into the lake from the catchment, frequent mixing of the lake, bottom sediment disturbances and algal growth. This corroborates the findings by Mugo (2010). According to the spatial results derived from this study, the lake was more turbid compared to the findings by Mwamburi et al. (2007), and Mugo (2010).

The higher temperatures recorded at Sewage Discharge Point and Mouth of R. Malewa stations are attributed to low secchi disc depth due to higher turbidity. High turbidity results from more suspended particulate matter, siltation, organic waste deposition, and surface run-off into the lake from the catchment leading to absorption of solar radiation hence higher temperatures. The findings in this study agree with ones found by Sitoki (2010) and Ogendi et al. (2015) in Lake Victoria. The low mean temperature recorded at Sher Bay and Crescent Island was attributed to the fact that these stations are found at the sheltered bays with high volumes of water hence takes a longer time to warm. The vegetation cover and the relatively higher lake depth at these stations prevent wind action hence no complete mixing and suspended particulate matter. The findings and observations made in this study agree with the ones found by Njuguna (1982), Kitaka (1991), and Mugo (2010) in Lake Naivasha and Gikuma-Njuru and Hecky (2005) in Lake Victoria. Single factor ANOVA showed no significant difference between the sampling stations, and this can be attributed to the fact that the lake is shallow with frequent mixing (Ndungu, 2014).

The low dissolved oxygen recorded at Crescent Island station (7.84 mg/L) can be attributed to higher phytoplankton diversity leading to more intake of oxygen during photosynthetic activity and organic waste degradation. The low dissolved oxygen at this station can also be attributed to partial stratification. This finding corroborates the findings made Hubble and Harper (2010) in L. Naivasha and Sitoki et al. (2012) in L. Victoria. The low dissolved oxygen levels recorded at the Mouth of R. Malewa can be attributed to the fact it lies at the point source of pollution hence a lot of inorganic, organic waste, siltation, and nutrient loading. Similar studies show that higher nutrient and organic waste loading into an aquatic system like L. Naivasha leads to higher microbial activity hence a reduction in dissolved oxygen due to decomposition (Njuguna, 1982, Kitaka, 1991 and Mugo, 2010). High dissolved oxygen recorded at some stations like Sher Bay, Mid-lake, and Hippo point can be attributed to well mixing of the lake water, absence of major influx and atmospheric oxygen. The amount of oxygen dissolved in water is highly influenced by water temperatures according to studies by Ndungu (2014). The high mean conductivity values recorded Sewage Discharge Point and Mouth of R. Malewa can be attributed to the fact that these stations act as conduits of sewage and organic matter, nutrients from the lake catchment and sedimentation hence higher temperatures leading to more solutes dissolving. Similar observation and finding were done by Lind (1965) (250 µS/cm), Kitaka (1991) (258.5 µS/cm) and Mugo (2010) (259 ± 23 µS/cm). Sewage Discharge Point had the highest mean pH and this can be attributed to higher organic waste loading hence an indication of higher rate of pollution. The high pH levels of L. Naivasha can also be associated with its geology that is mainly volcanic rocks. The low mean pH recorded at Crescent Island can be attributed to pollution from dissolved livestock waste within the sheltered bays, higher temperatures, and high levels of ammonium and nitrates. Mugo (2010) found similar findings.

The high levels of soluble reactive phosphorous at Sewage Discharge Point and Mouth of R. Malewa recorded can be attributed to increased turnover rates due to lake mixing and exogenous sources of pollution. The two stations are the main sources of pollution, hence more nutrient loads into the lake from agricultural catchment and organic waste from industrial and urban effluents. This finding collaborates the observations made by Kitaka (1991), Ballot et al. (2009), Mugo (2010) and Ndungu (2014). These studies have also revealed that the natural water quality of the lake is mainly influenced by solute inputs and the fluctuations in the lake level. Deterioration of aquatic quality in the tropics has been massively contributed by nutrient loading (phosphorous and nitrogen) leading to lake fertilization. The mean TP observations can be attributed to high organic materials and fertilizer loading into the lake from the main river discharges. Bottom sediment disturbances and discharge of untreated and partially untreated sewage waste from Naivasha municipality can be attributed to higher TP at Sewage Discharge Point. Also, of great importance source of nutrient in the lake is the mixing of the lake that distribute the nutrient in the entire column of the lake during strong wind. In shallow water, wind waves and current leads to resuspension of bottom materials and nutrients due to upwelling of the lake. Addition of nitrate-nitrogen to Phosphorous-rich water favors most algae community structure hence a higher algal biomass at Sewage Point. At present, most evidence shows that freshwater eutrophication ultimately arises from persistent increase in phosphorous influx from urban and other anthropogenic sources as was observed by Kitaka et al. (2002), Hubble and Harper (2002b), Mugo (2010), and Chin (2015). The higher concentrations of total nitrogen recorded at Sewage Discharge Point, Sher Bay, and Mouth of R. Malewa can be associated with nutrients loading from the flower farms, fertilizers from the agricultural farms in the catchment, municipal and sewage effluents, and storm water run-offs from non-point sources of pollution. This current study shows that mean TN levels are much higher than those found out by Mugo (2010) (304 µg/L ± 96 SD) and this can be attributed to effect of anthropogenic activities within the lake catchment and shores. However, TN levels of this study were much lower compared to those observed by Njuguna (1982) and Kitaka (1991) (1106-2509 µg/L). The low levels of Total Nitrogen recorded at Hippo Point can be attributed to partial lake stratification with minimal disturbance and the fact that it is a sheltered bay as was also found out by Hubble and Harper (2002). The higher concentrations for both nitrate nitrogen and ammonium nitrogen at Sewage Discharge point and Mouth of River Malewa stations can be associated with influxes of partially treated sewage wastes into the lake, fertilizer use in Lake Catchment and lakeside flower farms. Clearing riparian vegetation for agricultural production and upwelling of bottom sediments into the water column can also be associated with higher nutrients concentration at these stations. Previous studies by Njuguna (1982), Kitaka (1991), and Hubble and Harper (2001 and 2002b) associated the existence of various nitrogen forms to spatio-temporal distribution of organic waste, availability of macrophytes, temperature, dissolved oxygen, upwelling of bottom nutrients and the already existing levels of nitrate nitrogen and ammonium nitrogen in the lake. Nutrient levels dynamic in the lake have also been attributed to the lake level fluctuations that influence its area and productivity. According to the study conducted by Harper and Becht (2002), they classified L. Naivasha as moderately eutrophic as a result of higher nutritents loads into the lake from the point sources of pollution (R. Malewa Mouth and Sewage Discharge Point). The high levels of silicates concentrations at Sewage Discharge Point and Mouth of R. Malewa can be associated with sewage and municipal waste effluents, fertilizers from the flowers farms adjacent to the lakeshores, agricultural effluents from the lake's catchment and anthropogenic activities along the lakeshores. Oserian Bay and Mid-lake had the lowest silicates concentration levels and this can be attributed to the higher abundance of Bacillariophyceae (diatoms) and this collaborates with the studies conducted by Lung'ayia et al. *(*2001), Anderson et al. (2002), Hubble and Harper (2002a and 2002b), Sitoki (2010), and Ogendi et al. (2015). These studies have shown that Bacillariophyceae have a positive relationship with silicates.

The low phytoplankton biomass recorded by the families Dinophyceae, Euglenophyceae and Zygnematophyceae can be attributed to harsh environmental conditions within the lake leading to phytoplankton competition from the dominant taxonomic groups leading to competitive exclusion. The Dinophyceae biomass of Lake Naivasha may be successful probably due to the longer the mixing periods of the lake in an annual cycle (Moore, 1989). This may result in nutrient depletion and therefore potentially mixotrophic groups, especially the Dinophyceae which are able to resort to bactivory or phagotrophy are favoured in such lakes (Olrik, 1998; Lewis, 1978). The low occurrence of Dinophyceae family, especially the genera of *Ceratium* can be linked to lower salinity (0.09-0.13 ppt) levels of Lake Naivasha hence low reproductive rates. Kitaka (1991) also observed this from her study on phytoplankton productivity in Lake Naivasha. *Euglena* genera (*E. acus* and *E. virids*), *Phacus longicauda,* and *Trachelemonous* spp mainly dominated Sewage Discharge Point hence are water quality indicators. This can be attributed to the pollution status of the station from sewage effluents, municipal waste, organic matter, and higher nutrients levels from the point sources of pollution. Euglenophyceae are usually abundant in shallow eutrophic lakes and thrive in waters enriched with organic matter (Hutchinson, 1967) where they often co-dominate with the Chlorophyceae (Kalff, 1986; 2002) but are known to make negligible contribution to the phytoplankton biomass of relatively deep stratifying lakes (Kitaka, 1991) such as Lake Victoria. Bacillariophyceae are good competitors at low light conditions and are therefore favored during mixing periods when most other phytoplankton are limited by low light water climates. The higher representation of pennate Bacillariophyceae compared to the centric ones in the lake may be due to their morphology which helps reduce sinking (Graham & Wilcox, 2000; Morabito et al., 2007). They are also better competitors for silica at low silica concentrations (Tilman et al., 1982; Merceline et al., 2020) since silica levels may be low in the lake because of the high temperatures (and strong thermal stratification) and has an alkaline nature (basic pH) which tends to pull the available silica into the deep anoxic layer (Willen, 1991). The high prevalence of Bacillariophyceae, especially the genera *Aulacoseira* at Crescent Island, Mid-lake and Hippo point can be attributed to nutrients availability, lake mixing and low surface area to volume ratio hence low sinking rates. This finding corroborates the findings recorded by Hubble and Harper (2002). A study conducted by Hubble & Harper (2010) associated the dominance of *Aulacoseira* spp in the lake with low conductivity levels of less than 600 $\mu S\ cm^{-1}$. Increased prevalence of *Anabaena* spp at the Mid-lake station and Mouth of R. Malewa can be attributed to their tolerance to low dissolved oxygen, sensitivity to mixing and the fact that they belong to a group of algae that can fix nitrogen. *Anabaena* spp can also fix atmospheric nitrogen and have ability to move up and down in water column hence have got a greater advantage over other phytoplankton taxa (Kitaka, 1991; Mugo, 2010; Ndungu, 2014).

Cyanophyceae are capable of nitrogen fixation and buoyancy regulation (Paerl, 1996) and have very high affinity and uptake rates for phosphorus in addition to their ability to regulate their position in the water column (Reynolds, 2006). In nutrient deficient environments, Cyanophyceae tend to move between the light and nutrient fields to acquire essential nutrients needed for their metabolic activities enable them to out-compete other phytoplankton groups (Lewis, 1978; Paerl, 1996). Some Cyanophyceae such as the heterocyst-bearing filamentous forms which are abundant in the lake, are also able to fix nitrogen giving them a further advantage in stratified waters where bioavailable nitrogen (nitrates, nitrites and ammonia) is lost through denitrification to N2 (g) at the oxic-anoxic interface of the water column. Occurrence of *Microcystis* spp at Sewage Point and R. Malewa mouth has been associated with higher mixing rates leading to upwelling of bottom nutrients, nutrient rich waters, lake depth, and their buoyancy characteristics. These observations and findings corroborate the findings observed by Sitoki et al. (2012) in the Nyanza gulf of L. Victoria. Nitrate amendment favors initial growth of large centric diatoms, before giving way to colonial *Microcystis* spp. Some members of the phytoplankton community are often abundant in NO_3^-rich eutrophic waters, possibly because they exhibit higher affinity for NO_3. However, under conditions in which their growth becomes limited by the supply of phosphorous or light, dense proliferations of slower-growing *Microcystis* spp. can replace diatoms. A species is favored when both absolute concentrations of nitrogen and phosphorus and their ratio in the environment conform to that particular species' requirements according to Hubble & Harper (2002). The higher Chlorophyceae biomass in this study can be associated with favourable environmental factors like light regime, availability of essential nutrients and lake depth. Studies done by Kitaka (1991) and Ballot et al. (2009) have also shown that Chlorophyceae depict a positive correlation to shallow water, favourable temperature, and good tidal exposure (mixing). A study by Njiru et al. (2014) on some aspects of feeding ecology of Nile tilapia, *Oreochromis niloticus* in Lake Naivasha has shown that *O. niloticus* has got spatial variation in their diet with regard to phytoplankton. The study revealed that algae contributed the biggest proportion among its diverse diet with majority of its feeding being on the open waters. Straus Linear index of food selection also shows that Nile tilapia preferred Chlorophyceae but avoided algae in the other families like Bacillariophyceae and Cyanophyceae (Njiru et al., 2014). This could be attributed to the fact that diatoms have tough cell walls that are harder to digest as compared to green algae. Cyanobacteria are filamentous and hence more difficult to handle during feeding and can lead to clogging of fish gills. Some Cyanobacteria like *Microcystis* spp are also known to produce toxins i.e. Microcystins. This could explain the avoidance of some of them by the fish in their diet. This can be the probable explanation of the high biomass of Cyanophyceae and diatoms.

Chroococcus spp, *Lyngbya* spp, and *Planktolygbya* spp domination of Cyanophyceae biomass in this study can be attributed to high organic loading, increased nutrients loads, higher competition rates, and polymictic nature of the lake that suspends bottom nutrients. These findings corroborate the observation made by Ogendi et al. (2015) in Lake Victoria on the effects of point sources of pollution on water quality and phytoplankton community structures. *Closterium* spp and *Cosmarium* spp biomass dominated the family Zygnematophyceae throughout the entire study period and this can be attributed to nutrients inputs especially nitrates into the lake and secchi depth leading their species richness. During the high-water level, phytoplankton structure was dominated by *Aulacoseira* spp, *Scenedesmus* spp. *Pediastrum* spp, *Monoraphidium* sp, *Tetraedron* spp and *Botyococcus braunii*. This can be attributed to nutrients inputs by river discharges, water turbulence, and organic matter. There was a rather slow change in algal communities in Lake Naivasha during this study, which may be due to high frequency of lake level fluctuation resulting in constant presence of some species adapted to water turbulence and level fluctuation disturbances. Although Lake Naivasha is shallow, there is a predictable seasonal succession of phytoplankton. Periods of stable stratification with maximum light availability and low nutrient supply favor Chlorophyta especially certain colonial species of Chlorococcales. Phytoplankton species composition and their biomass showed spatial variation. This was corroborated by PCA (Bi-plot) and correlation done between the physico-chemical parameters and phytoplankton families. Cyanophyceae abundance dominated Sewage Point, Mid-lake, and Crescent Island. This can be associated with the high concentrations of Total Phosphorous, Total Nitrogen, ammonium nitrogen and soluble reactive phosphorous. Similar studies by Njuguna (1982), Kitaka (1991), Sitoki (2010), Sitoki et al. (2012), and Ogendi et al. (2015) also found out that blue-green algae flourishes in waters with favourable environmental factors. The factors attributed to their abundance were nutrients, light conditions, and greater mixing depth. Principal Component Analysis showed positive correlation between Diatoms, pH, dissolved oxygen, and temperature at Hippo Point station. The low abundance of Bacillariophyceae at the Mouth of R. Malewa and Mid-lake can be attributed to the harsh environmental conditions provided by Cyanophyceae because of competition for nutrients, light, and their buoyancy characteristics. Chlorophyceae abundance was high at Crescent Island, Mid-lake, and Hippo Point. This can be attributed to favourable light conditions, good water temperature ranges and nutrients availability. PCA biplot showed that Sewage Discharge Point was linked to Euglenophyceae and this is because of high organic matter, nutrients availability, sewage, and municipal effluents.

The dominance of Cyanophyceae biomass at Sewage Point, Mid-lake, and Oserian Bay can be associated with the high concentrations of Total Phosphorous, Total Nitrogen, ammonium nitrogen and soluble reactive phosphorous as depicted by PCA. Similar studies by Njuguna (1982), Kitaka (1991), Sitoki (2010), Sitoki et al. (2012), and Ogendi et al. (2015) also found out that blue-green algae flourish in eutrophic waters with greater mixing depth. The proliferations of Bacillariophyceae showed a positive correlation to temperature with higher biomass at the Mouth of R. Malewa and Hippo Point. These stations have been characterized with elevated levels of nutrients levels, good mixing rates, and favourable temperatures. The low abundance of Bacillariophyceae at Sher Bay can be attributed to the harsh environmental conditions provided by other phytoplankton taxa because of competition for nutrients, light, and their buoyancy characteristics. The higher biomass of Chlorophyceae at Crescent Island, Mid-lake, and Oserian Bay attributed to favourable light conditions, good water temperature ranges and nutrients availability. PCA bi-plot showed that Sewage Discharge Point was linked to Euglenophyceae and this is because of high organic matter, nutrients availability, sewage, and municipal effluents (Rayori et al., 2025). Cyanophyceae biomass dominated the months of February and June. The dominance of blue-green algae in the month dry months of February can be attributed to higher temperatures, favourable light conditions, and increased dissolved nutrient concentration due to evaporation from high solar radiation. Their dominance in the wet month of June can be attributed to higher nutrient loading from discharges from Rivers Malewa, Karati and Gilgil passing through the lake's agricultural-based catchment. High nutrients and fertilizer loads can also be linked to the storm waters and surface run-offs from the flower and horticultural farms adjacent to the lake. The rainy season causes water agitation leading to higher turbidity, hence elevated water temperatures. A study done by Ogendi et al. (2015) also linked favourable temperatures to higher algal photosynthetic activity.

Conclusions and Recommendations

Nutrient enrichment in inland waters poses serious health problems to the users and aquatic biodiversity. The nutrient levels in the lake are high, showing that the lake is eutrophic with respect to total phosphorus, and total nitrogen. Two-point sources for these nutrients were identified as Sewage Discharge Point and Mouth of R. Malewa. Their contribution to lake's nutrient enrichment was prominent during the wet season when there was an increased surface run-offs, river discharge and sewage effluent. Water quality status of L. Naivasha is mainly influenced by anthropogenic activities within the lake catchment. Lake Naivasha has a greater diversity of phytoplankton community with the biomass dominated by the family Chlorophyceae. Also, anthropogenic activities and environmental conditions are the major factors for the high diversity of phytoplankton in the lake. Phytoplankton community structure shows a greater relationship to physico-chemical parameters of the lake especially dissolved oxygen, soluble reactive phosphorous, total phosphorous, total nitrogen, silicates, temperature, and depth. Therefore, there is need to monitor the discharge of pollutants from point and non-point sources. Further, conservation measures should be undertaken to restore the limnological integrity of the lake. These findings provide a baseline for future related studies to be conducted in assessing the interactions between nutrient levels and phytoplankton biomass, diversity and distribution in this lake and other related ecosystems.

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Conflict of Interests

The author declares no conflict of interest.

Availability of Data and Materials

The necessary data is available upon request from the corresponding author.

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