OPEN ACCESS
International Journal of Aquatic Science
ISSN: 2008-8019
Vol. 10, No. 2, 101-111, 2019

IJAS

Temporal variation in physico-chemical characteristics, phytoplankton composition and biomass in Lake Solai, Kenya

Eunice C. Koskei[1]*, Kiplagat Kotut[2], Justin Nyaga[3] and Steve Omondi Oduor[4]

1) University of Embu, P.O. Box 6 - 60100, Embu, Kenya.
2) Department of Biological Sciences, University of Embu, P.O. Box 6 - 60100, Embu, Kenya.
3) Department of Biological Sciences, University of Embu, P.O. Box 6 - 60100, Embu, Kenya.
4) Department of Biological Sciences, Egerton University, P.O. Box 536 - 20115, Egerton, Kenya.

Received: August-21-2019 **Accepted:** October-14-2019 **Published:** October-20-2019

Abstract: The physico-chemical properties and phytoplankton community structure of Lake Solai were investigated between April 2018 and August 2018. Water temperature, conductivity (EC), dissolved oxygen (DO) content and pH were measured in-situ. Nutrient content and phytoplankton biomass were determined in the laboratory. All the water properties; temperature (mean: 23.19 ± 0.13 °C), DO (mean: 6.35 ± 0.03 mgL^{-1}), total suspended solids (TSS) (mean: 220.85 ± 8.11 mg L^{-1}), turbidity (mean: 702.51 ± 9.40 NTU), nitrate nitrogen (NO_3-N) (mean: 0.75 ± 0.02 mg L^{-1}) total phosphorus (TP) (mean: 20.57 ± 0.51 mg L^{-1}) showed significant temporal variation ($P<0.001$). Five groups of phytoplankton were identified; Cyanobacteria, was the most dominant with 14 species, Chlorophyta (11 species), Bacillariophyta (8 species), Euglenophyta (3 Species) and Chrysophyta (2 species). The high TP concentration makes it a eutrophic system. The high turbidity create a poor light climate that select against a number of biota that could inhabit the lake allowing for few algal organisms, especially the Cyanobacteria that have the potential to exploit this niche and establish potentially harmful algal blooms. The DO levels were within the permissible limits recommended for fisheries and aquatic life. Hence, the possibility of introducing salt tolerant fish should be explored.

Keywords: Physico-chemical properties, Lake Solai, Eutrophic, Turbidity, Biomass

Introduction

The quality of an aquatic ecosystem is dependent on the physico-chemical conditions of its water and its biological diversity (Vanitha and thatheyus, 2016; Irfanullah, 2006). Anthropogenic activities such as wastewater discharge and abstraction can alter the physico-chemical properties and hence change the water quality and quantity, species distribution and diversity, production capacity and even disrupting of the ecological balance operating in the lake (Dhanam *et al.*, 2016). Water contains a vast array of chemicals whose interactions with the physical environment influences the composition, distribution and abundance of aquatic organisms in the given aquatic ecosystem. This therefore dictates the extent to which a lake ecosystem may be used sustainably.

Lake Solai is one of the small ephemeral alkaline lakes located in Nakuru County, Kenya- within a semi-arid region on the floors of the Eastern arm of the African Great Rift Valley. The lake lies between two major flamingo lakes, Lake Nakuru and Lake Bogoria and is occasionally visited by flamingoes. Its endorheic nature and the evaporative concentration of dissolved solutes, mainly the carbonates and bicarbonates, driven by the prevailing high temperatures have contributed to its alkaline state. However, the community living around the lake treat it as a freshwater body and use its water for irrigation, watering of livestock and other domestic purposes. The high water abstraction from the lake due to its demand for irrigation, its arid location and the high temperatures have made the lake dry up several times in the last 40 years (Goman, 2017).

Though the lake is an important source of water for humans and wildlife in the area, it has not been studied much as other Rift Valley Lakes and as such, very little is known about its physico-chemical environment conditions. Most limnological studies in the region have focused mainly on the larger and more permanent lakes of the Rift Valley (Ouma and Mwamburi, 2014; Melack, 1988; Ballot *et al.*, 2009).

Materials and methods

Study area and site

Lake Solai (Fig. 1) is a shallow alkaline lake located in a semi-arid region of the Eastern Rift Valley to the NE of Nakuru town along the Nakuru-Nyahururu road, approximately 50 km from Nakuru town. It lies between 0º 30' 0" N and 36º 9' 0" E at an elevation of 1667m ASL. The lake has a maximum depth of 1.5 m and a total area of 9 km^2 that however fluctuates

(✉) koskei_e@yahoo.com

depending on the meteorological condition in the surrounding area. The vegetation fringing the lake is dominated by Acacia woodland to the west and south, with *Cynodon dactylon L.* dominating the herbaceous zone beneath the woodlands. To the east and south of the lake, saline swamps dominated by *Sporobolus robustus* Kunth occurs next to the edge while *Cyperus laevigatus* L. is found in regions that experience prolonged dry periods. Rooted plants (*Typha domingensis* Kunth) characterize the shores of the lake and a floating aquatic flora (*Ludwiga stolonifera* (Guill andal*)* and *Pistia stratiotes* L., occurs along the Delta of Maji tamu inflow (De Bock *et al.*, 2009). The community living around Lake Solai practice agro-pastoralism in which they use the land around the lake for cattle grazing, particularly during the dry season, and maize growing along several stream systems (De Bock *et al.*, 2009). Along the shores of the lake, vegetables are grown using water from the lake for irrigation.

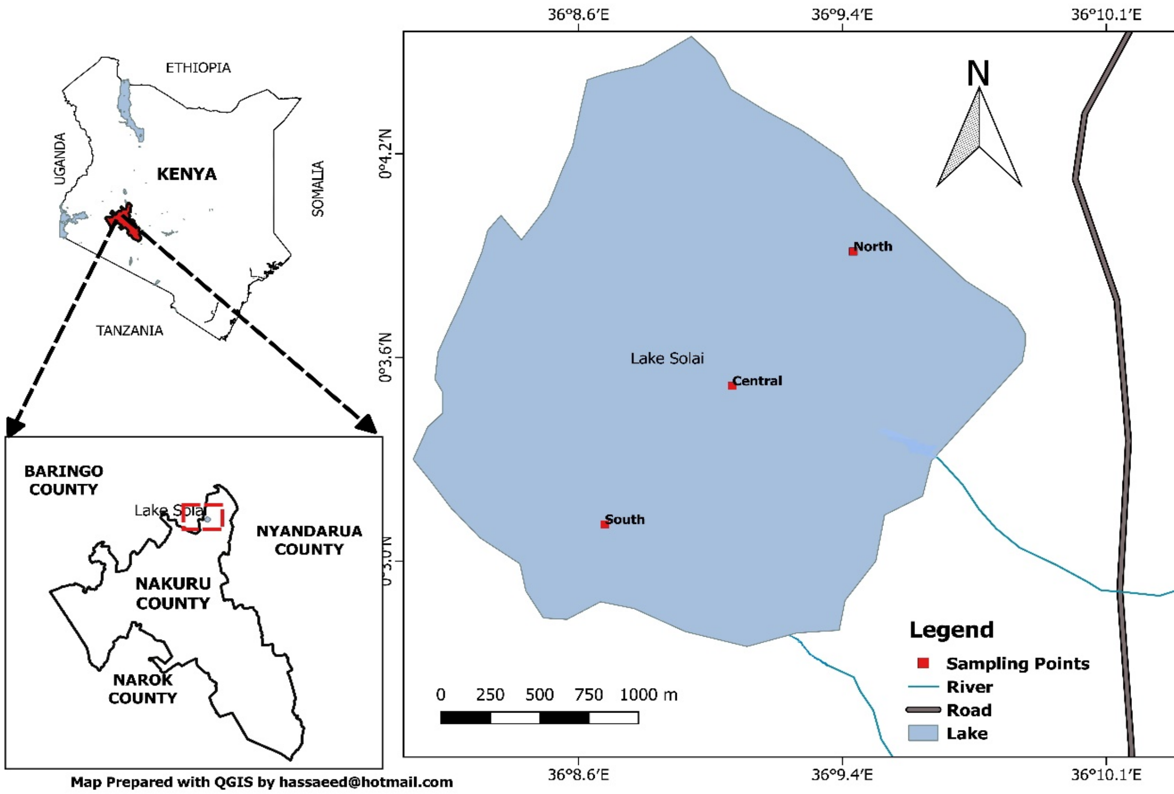

Fig. 1: Map of Lake Solai showing the sampling sites, the points marked in red.

The lake is fed by a small stream known as Chesebet (Maji tamu), a seasonal stream that dries up during periods of extreme drought. Other streams such as, Kasururei and Chemuka used to drain into the lake but have since been diverted for irrigation. The major input of water into this lake is mainly through precipitation and surface runoff while water loss occur through evaporation. The watershed receives between 700-900mm of precipitation per year. However, potential evaporation is very high (approximately 1800 mm year^{-1}), resulting in negative hydrological budget (Goman *et al.*, 2017).

Sampling

Sampling was carried out fortnightly from April to August 2018. Samples were collected from three sampling points along a North-South transect in the lake. The three points were, North (N00˚03.914' E036˚09.391'), South (N00˚03.516' E036˚09.061') and Central (N00˚03.106' E036˚08.709'). Water samples for determination of nutrient concentration and phytoplankton biomass were collected at the surface (approximately 5 cm from the surface), mid-depth (1 m) and near the bottom (1.5 to 2m) using Schindler sampler, packed in sample bottles and transported to Egerton University Biological Sciences Department Limnology laboratory under cool box for various limnological parameters analyses.

Determination of physico-chemical properties

Temperature, pH, electrical conductivity and salinity were measured in-situ using the HACH HQ 40d meter. Dissolved oxygen content was measured using the HACH HQ 30d meter. Nutrient concentration in the water was determined from the collected water sample which were analyzed in the laboratory following the standard methods as described in APHA (2005).

Phytoplankton composition and biomass

Water samples drawn from appropriate sections of each sampling station was collected for laboratory analyses of phytoplankton properties (identification, counting, biomass and diversity). At each sampling site, net samples were collected for the determination of phytoplankton using a phytoplankton net of mesh aperture 20 µm .A portion of the sample collected was preserved in acidified Lugol's solution for phytoplankton density determination (Fathi and Flower, 2005). In the laboratory, the phytoplankton species composition was determined using a trinocular compound microscope (Zeiss, primo star model). Species identification was done with the aid of reference materials such as publications on East African Lakes (Talling,1989) and other available keys (Tomas, 1997; Lund and Lund, 1995; Johnson, 2002).

Cell counting for the determination of phytoplankton density was carried out in a Zeiss, primo star model microscope at X400 magnification (Utermöhl, 1958; APHA, 2005; Lund and Lund, 1996).The Sedgewick rafter counter cell chamber was filled with 1mL of a well-mixed phytoplankton sample and left standing for at least three hours for complete cell sedimentation to occur. Counting of the coccoid cyanobacteria was based on ten randomly selected fields while counting of the larger algae was based on transect. The whole bottom area of the chamber was examined for the large and rare taxa under low (X100) magnification. The counting was done on all individual cells, colonies, and filaments. Biovolume determination was made based on the individual cell dimensions with respect to their geometrical shapes that include spheres, rotational ellipsoid with circular cross-section, cylindrical and cone shapes (Hillebrand *et al.*, 1999; Wetzel, 2013).

Results

Physico-chemical properties

Lake water temperature ranged from 21.0 °C recorded in August on 08/08/18 at the North sampling site to 30.4 °C recorded in April on 18/04/18 at the South sampling site with a mean temperature value of 23.3 ± 0.10 °C (Fig. 2a). There was a general decline in temperature from the surface to the bottom waters. A high fluctuation of temperature was recorded at the surface, with slight fluctuation at the bottom. Dissolved oxygen (DO) concentration recorded ranged from 4.10 mg L^{-1} recorded in the South sampling site on 30/05/18 to 9.4 mg L^{-1} recorded in the North sampling site on 16/05/18 with a mean of 6.35 ± 0.03 mg L^{-1} (Fig. 2b). Except for a very high value of DO recorded on 16/05/18, the DO values were generally stable with slight fluctuation recorded. Electrical conductivity (EC) ranged from 1414 µS cm^{-1} recorded at the Central surface sampling site on the 25/07/18 to 2900 µS cm^{-1} recorded on 08/08/18 at the Central surface sampling site with a mean concentration value of 1924.92 ± 27.11 µS cm^{-1} (Fig. 2c). A progressive decline in EC was recorded from April to July after which it increased in early August. Salinity ranged from 0.77 ‰ recorded on 25/07/18 at the North sampling site to 1.47 ‰ recorded at the South sampling site on 22/08/18 respectively with a mean value of 0.98 ± 0.02 ‰ (Fig.2d). There was reduction in salinity from April to July; it then rose sharply in August. The TSS ranged from 20 mg L^{-1} at the North sampling site on 25/07/18 to 790 mg L^{-1} recorded at the South sampling site on 06/05/18 with a mean value of 220.85 mg L^{-1} (Fig. 2e). The TSS values kept reducing from April to July, then increased slightly in August. Mean comparison of the various physico-chemical properties using a one-way analysis of variance test revealed that all of them showed a significant temporal variation in the different sampling dates ($P < 0.0001$, DF = 269). Lake water pH remained alkaline throughout the sampling period with a range from 8.8 to 13.2 recorded at the North surface on 15/7/18 and on the Central surface on 02/05/18 respectively. The pH values recorded were generally stable throughout the sampling period; however, two peak periods were recorded on 16/05/18 and 27/06/18 (Fig. 2f).

Among the nutrients, nitrate-nitrogen (NO_3- N) varied from 0.01 mg L^{-1} recorded on 22/08/18 at the North sampling site to 1.44 mg L^{-1} recorded on 27/06/18 at the Central sampling site with a mean value of 0.75 ± 0.02 mg L^{-1} (Fig. 3a). The values of NO_3- N fluctuated during the early months (April to Mid July) the reduced sharply in August. Total phosphorus (TP) levels ranged from 2.77 mg L^{-1} recorded at the South sampling site on 18/04/18 to 38.10 mg L^{-1} recorded on 16/05/18 at the South sampling site with a mean concentration value of 20.57 ± 0.51 mg L^{-1} (Fig. 3b).

Wide fluctuations of total phosphorus were recorded at the beginning but the values stabilized by mid-June. Comparison of mean of both TP and NO_3- N of the different sampling dates using a one way ANOVA test revealed a significant temporal variation ($P < 0.0001$, DF = 269).

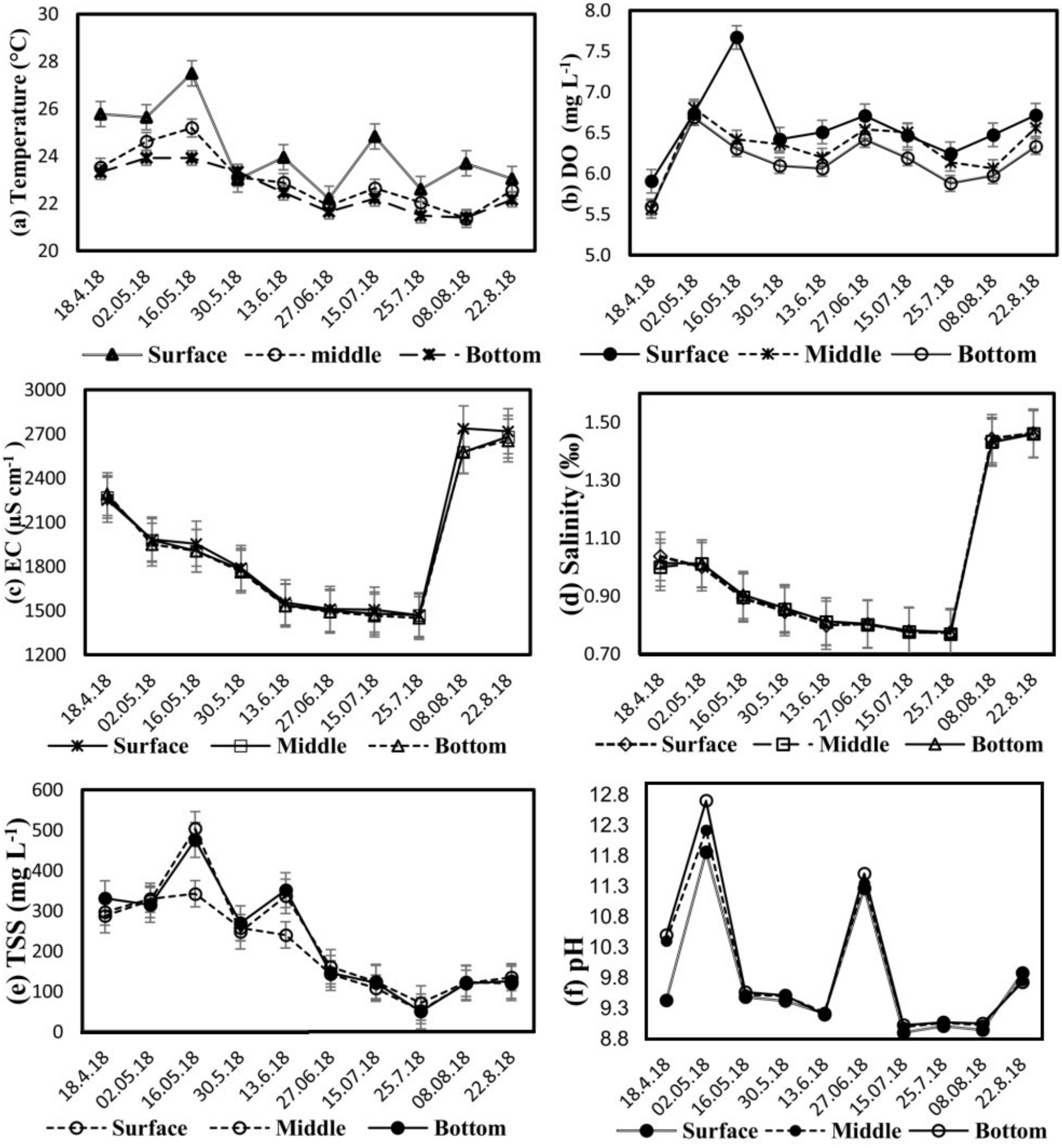

Fig. 2: (a-f) Temporal variation of physico-chemical properties (mean ± SE) of Lake Solai during the sampling period April 2018 to August 2018.

Phytoplankton community structure in Lake Solai

A total of 38 phytoplankton species belonging to five phytoplankton divisions were identified in Lake Solai during the sampling period (Tab. 1). The divisions represented in the lake phytoplankton are the Cyanobacteria, Euglenophyta, Chlorophyta, Bacillariophyta and Chrysophyta. Numerically, the Cyanobacteria had the highest number of species (13) which accounted for 38% of the species identified. The Chlorophyta with 12 species (28%), Bacillariophy*ta* had 8 Species (21%), Euglenophyta with 3 species (8%) and Chrysophyta with about two (2) species (5%) followed respectively.

Tab. 1: Checklist of phytoplankton groups observed in Lake Solai during the sampling period April 2018 to August 2018 (+ present - absent). Sample No. 1 – 10 represents the different sampling dates during the sampling period

DIVISION	1	2	3	4	5	6	7	8	9	10
CYANOBACTERIA										
Microcystis sp.	+	+	-	+	+	+	+	+	+	+
Chroococcus sp.	-	+	-	-	-	+	-	+	+	+
Anabaena sp.	+	-	+	+	+	+	+	+	-	+
Nodularia sp.	-	-	-	+	+	+	-	+	-	-
Lyngybya sp.	-	-	-	-	+	-	-	-	-	-
Aphanothece sp.	-	-	-	-	-	-	-	+	+	+
Rivularia sp.	-	-	-	-	-	+	-	+	+	-
Aphanizomenon sp.	-	-	-	+	+	+	-	+	-	-
Pseudoanabaena sp.	-	-	-	-	+	-	-	-	-	-
Cylindrospermosis sp.	-	-	-	-	+	-	-	-	-	-
Aphanocapsa sp.	-	-	-	-	-	-	-	+	-	-
Oscillatoria sp.	-	-	+	-	+	+	-	+	+	+
Nostoc sp.	+	-	-	-	-	-	+	-	-	-
EUGLENOPHYTA										
Euglena sp.	+	+	+	-	+	+	+	-	-	+
Trachelomonas sp.	-	-	+	-	+	+	-	+	+	+
Phacus sp.	-	+	-	+	+	+	+	+	+	+
CHLOROPHYTA										
Pediastrum sp.	-	-	-	-	-	+	-	-	-	+
Chlorella sp.	-	+	+	+	+	+	+	+	+	+
Anskinstrodesmus sp.	-	-	-							
Pandorina sp.	-	-	-	-	-	+	-	-	-	-
Dictyosphaerium sp.	-	-	-	-	-	-	-	+	+	-
Chlamydomonas sp.	-	-	-	-	+	-	-	-	-	-
Coelastrum sp.	+	-	-	-	+		+	-	-	-
Characium sp.	-	-	-	-	-	+	-	-	-	+
Eudorina sp.	-	-	-	-	-	+	-	-	-	-
Scenesdesmus sp.	-	-	-	-	-	-	-	-	-	+
Tetraselmis sp.	-	-	-	-	-	-	+	-	-	+
Closterium sp.	+	-	-	-	+	+	-	-	+	+
BACILLARIOPHYTA										
Cocconeis sp.	+	+	-	-	+	-	-	-	-	-
Cyclotella sp.	-	-	-	-	-	+	-	-	-	+
Navicula sp.	+	-	-	-	-	+	-	+	+	+
Nitzschia sp.	+	-	-	-	-	-	+	+	+	+
Fragilaria sp.	+	-	+	-	-	+	-	+	-	-
Diatoma sp.	-	-	-	+	-	-	-	-	-	-
Eunotia sp.	-	-	-	-	-	-	+	-	-	-
Cymbella sp	+	-	-	-	-	-	-	-	-	-
CHRYSOPHYTA										
Dinobryon sp.	-	-	-	-	-	+	-	-	-	-
Chromulina sp.	-	+	-	-	+	-	-	-	-	-

The total biomass in terms of biovolume fluctuated during the sampling period with the least (1.0×10^{6} µm^3 L^{-1}) being recorded on 25/7/18 and the highest (1.8×10^7 µm^3 L^{-1}) being recorded on 16/5/19. The phytoplankton biomass was generally low and varied over time at the different sampling sites. Cyanobacteria with a biomass contribution of 51.71%, was the dominant phytoplankton group in Lake Solai during the sampling period followed by Euglenophyta (33.67 %), Chlorophyta (11.86 %), Bacillariophyta (2.64 %) while the least dominant was the Chrysophyta with a very low biomass contribution of 0.12%. The highest Cyanobacteria biovolume (9.7×10^5 µm^3 L^{-1}) was recorded on 27/06/2018, while the least (2.4×10^4 µm^3 L^{-1}) was recorded on 13/06/2018. The Bacillariophyta recorded a high biovolume (6.6×10^5 µm^3 L^{-1}) on 16/05/18. The lowest biovolume was recorded on 30/05/19 and on 25/07/18. Chlorophyta recorded 4.96×10^6 µm^3 L^{-1} (90.10 %) biovolume on 16/05/18. Generally, the biovolume of Chlorophyta on other sampling dates was low with the least 3.5×10^3 µm^3 L^{-1} being recorded on 15/07/18. Euglenophyta recorded 1.1 x 10^7 µm^3 L^{-1} biovolume on 16/05/18 and 3.28 x 10^6 µm^3 L^{-1} recorded on 02/05/18. Generally, biovolume on most of the other sampling dates was very low, the least being recorded on 30/05/18. Chrysophyta was poorly represented throughout the sampling period (Fig. 4).

The phytoplankton community structure in Lake Solai revealed that the most dominant species of the Cyanobacteria in terms of biovolume was *Microcystis* sp. and *Anabaena* sp. Euglenophyta was dominated by *Euglena* sp. *Trachelomonas* sp. and *Phacus* sp. The dominant species recorded for Chlorophyta was *Chlorella* sp. Bacillariophyta was dominated by *Navicula* sp. and *Nitzschia* sp. The Chrysophyta was poorly represented throughout the sampling period with only two species, *Dinobryon* sp. and C*hromulina* sp. appearing occasionally (Fig. 5).

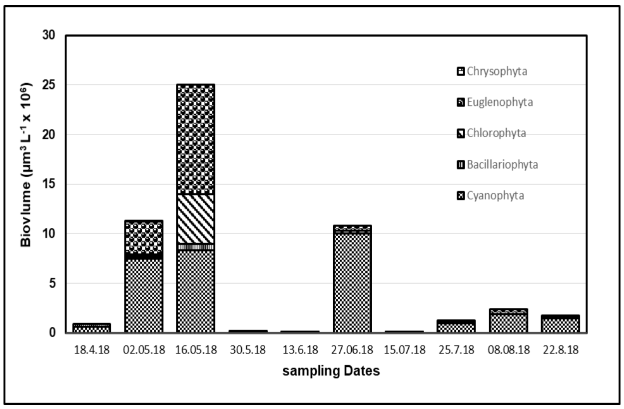

Fig. 3: Temporal variation in the biovolume of various phytoplankton groups in Lake Solai during the sampling period April 2018 to August 2018.

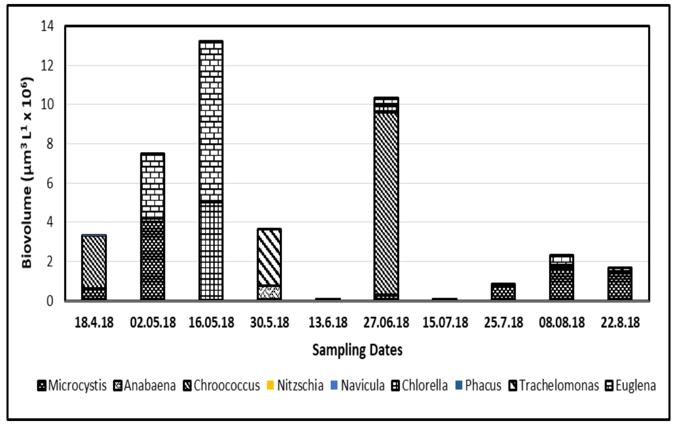

Fig. 5: Temporal variation in the biovolume of the most dominant species in Lake Solai during the sampling period April 2018 to August 2018

There was a progressive increase in species diversity from April to August. The highest species diversity (1.60 ± 0.11) was recorded on 22/08/18 while the lowest 0.14 ± 0.04) was recorded on 18/04/18 (Fig. 6).

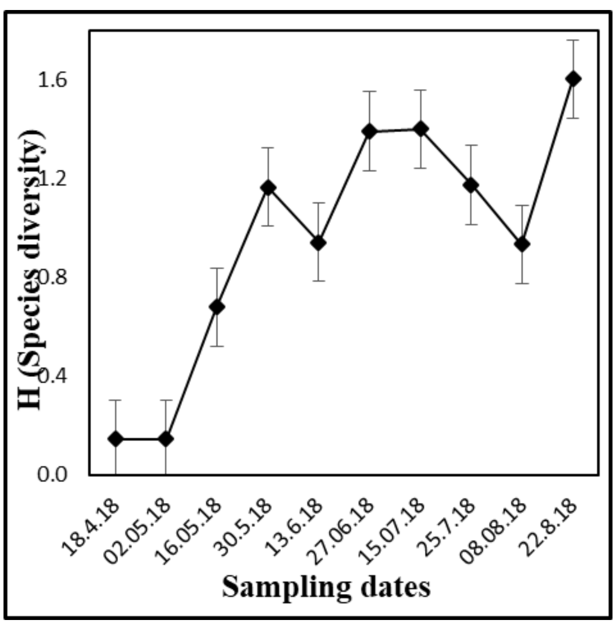

Fig. 6: Temporal variation in phytoplankton species diversity recorded in Lake Solai during the sampling period April 2018 to August 2018.

Discussion

Physico-chemical properties

The physico-chemical properties of Lake Solai varied significantly in the different sampling dates. The highest temperature was recorded during the dry season when the weather conditions were characterized by a clear sky, high solar radiation, and low relative humidity. A similar observation was made by Varadharajan (2014) who stated that water temperature largely depends on the intensity of solar radiation, evaporation, insolation and fresh water influx. On the other hand, a combination of a depressed ambient temperature during the rainy season and increased inflow of cool water through the seasonal streams brought about the comparatively low water temperatures recorded in late June on 27/06/18. A decline in water temperature with lake depth that resulted in a significant difference in mean water temperatures of the depths studied was noted during the study. The drop in temperature with depth can be attributed to the absorption of most light near the water surface resulting in comparatively higher temperatures near the surface. Light reaching the water surface is either absorbed or scattered by suspended particles, dissolved substances, and the water itself. The mean temperature variations in Lake

Solai (23.26 ± 0.10) compares closely with a value of 23.1 ± 2.3 °C recorded in Lake Elementaita by Oduor and Schargel (2007) during a similar limnological study.

The highest value of dissolved oxygen recorded in early May can be attributed to the high phytoplankton biomass recorded during this period and the high inflows due to the onset of the rainy season. On the other hand, the low DO levels recorded in late May possibly resulted from the low phytoplankton biomass recorded at this time. A significant difference in mean lake DO values of the different sampling dates was noted during the sampling period ($P < 0.0001$, DF = 269). This could be attributed to a combination of the changes in mean lake phytoplankton biomass and variation in the organic matter load of inflows. A slight decline in DO with depth with a higher value recorded on the surface is indicative of a continuous mixing regime in the lake that does not allow for a built up of deoxygenated water at the bottom depths, this agrees with observation by Vijayakumar (2000)The mean DO concentration values (6.35 ± 0.03 mg L^{-1}) recorded in Lake Solai during this sampling period was lower than the levels recorded in other Rift Valley lakes; lakes Bogoria (13.1 ± 1.3 mg L^{-1}), Nakuru (17.1 ± 0.9 mg L^{-1}) and Elementaita (9.2 ± 0.8 mg L^{-1}) by Schagerl and Oduor (2007) in a similar study. The lower DO values could be attributed to the lower phytoplankton biomass in the lake as compared to other Rift Valley lakes. This suggests that unlike Lake Bogoria, Nakuru and Elementaita where DO levels are largely controlled by the phytoplankton photosynthetic activity, the dissolved oxygen levels in Lake Solai is mainly the result of diffusion exchange with the atmosphere. The DO values recorded in lake Solai is suitable for fisheries and aquatic life according to the values (5.0 – 9.0 mg L^{-1}) given by WHO (2011).

The pH value of a water body influences many water properties, processes and reactions (George *et al.*, 2013). Changes in pH in aquatic ecosystems may be driven by the removal of dissolved CO_2 in water through photosynthesis, fresh water influx, and decomposition of organic matter (Rajasegar *et al.*, 2003). In Lake Solai, pH was alkaline throughout the sampling period ranging from 9.0 to 11.0 with almost uniform values recorded throughout the sampling period. There were two-peak periods of pH recorded in Lake Solai, which coincided with the period of high phytoplankton biomass in mid-April, and late June respectively which possibly meant a greater uptake of CO_2 resulting in elevated pH values. The pH in lake Solai was in the same range as that observed in Lake Baringo (8.0 – 10.5) by Schagerl and Oduor (2007). There were two-peak periods of pH recorded in Lake Solai, which coincided with the period of high phytoplankton biomass in mid-April, and late June respectively. Hence, the low pH could be attributed to the low phytoplankton biomass recorded during this time.

Electrical conductivity (EC) is a measure of ionic content in the water (Gupta *et al.*, 2008). Its temporal variation reflects changes in water level as the lake receives runoff from the lake's catchment, and the ion exchange between the water and the sediments (Manohar *et al.*, 2016). The high electrical conductivity in August is associated with reduction in the water volume getting into the lake through the seasonal streams being lower than the rate of evaporation increasing the concentration of salinity content hence increasing its conductivity. Since the lake has no outlet, these solutes accumulate resulting in an increase in conductivity. Salinity plays a key role as a limiting factor since it controls the faunal and floral diversity of ecosystems, this is because most aquatic organisms restrain their ionic balance and osmotic pressure to a limited range of salinity (Zafar, 2018). Apparently, there were no wide variations in salinity in Lake Solai during the sampling time. Comparatively, the salinity levels in Lake Solai were lower than the values recorded for the neighboring Lakes Nakuru (49 ± 0 ‰), Bogoria (18 ± 0 ‰) and Elementaita (26 ± 0 ‰) (Oduor and Schargel, 2007). Changes in salinity for small water bodies is strongly influenced by the amount of inflows in such systems as was observed in August when it rose significantly.

The total suspended solids (TSS) and turbidity are interrelated and are the most visible indicators of water quality. High levels of TSS has the potential of increasing water temperature and decreasing dissolved oxygen concentration levels. Suspended solids also influence metabolic activity and provide surface area for the sorption and transport of an array of constituents (Varadharajan and Soundarapandian, 2014), these particles absorb heat from solar radiation, which is transferred to the surrounding water by conduction (Wetzel, 2001). The high TSS values observed in Lake Solai was as a result of the introduction of particulate matter by surface runoff and river inflows. Hence changes in quality and clarity of Lake Solai is largely dependent on TSS (Goman *et al.*, 2017). It is estimated that there are 40,000 head of cattle and more than 60,000 sheep and goats within

Lake Solai region (Kervyn de Meerendre, 2004). These animals are grazed within the vicinity of the lake and most of them are watered in the lake and this increases loose soil that is swept into the lake by surface run-off. This is a common feature of areas subjected to overgrazing (Kiage, 2007). A major consequence of an increase in livestock is increased soil erosion resulting in a high sediment loading to water bodies within the catchment. According to Goman (2017), increase in soil erosion and land degradation has been on the increase for at least fifty years in Lake Solai.

In June, there was increased inflow into the lake by the seasonal stream due to rains. The high nitrate values in June may be associated with the surface runoff from nearby farms containing fertilizers and pesticides used during cultivation. As pointed by Oduor *et al.* (2003) and Kotut *et al.* (1999), following the resumption of river flow by a seasonal river, large amounts of organic and inorganic matter accumulated over the dry season on the river and streambeds and within the catchment area are all swept downstream by the first floods. Symader and Bierl (1998) have also reported on the link between high nitrate nitrogen levels and the early rainy season. The low values recorded in early august may be attributed to reduction in freshwater inflow into the lake. The mean concentration of nitrate levels in Lake Solai (75.0 ± 0.02 mg L^{-1}) were in the same range with those observed in Lakes Bogoria (66.3 ± 3.6 mg L^{-1}) and Elementaita 71.6 ± 4.6 mg L^{-1}). However, this value was higher than the permissible limits for drinking water (50 mg L^{-1}) (WHO, 2011).

Phosphorus plays an important role in lake eutrophication of lakes (Ongom *et al.*, 2017). Orthophosphate phosphorus (PO_4-P) is the most important form of phosphorus for the growth of phytoplankton (EPA, 2001. The high total phosphorus recorded in Lake Solai can be attributed to farming activities in the surrounding areas that use fertilizers. During the rainy season, run-off containing farm fertilizers are swept into the lake contributing to the high phosphorus load. The grazing of livestock around the lake may also contribute to increase in the phosphate levels through their droppings. Owing to the shallow lake depth, water mixing by winds during, or at the onset of the rainy season, may lead to regeneration and resuspension of phosphorus from the bottom sediments leading to its increase in the water (Anita *et al.*, 2011). Utilization by the phytoplankton and adsorption to particulate matter and sediments could be attributed to the low levels of phosphorus recorded in Lake Solai during the sampling period, an observation that has been recorded elsewhere by Melakua *et al.*, (2007) and Varadharajan *et al.*, (2014). The observed significant variation of phosphorus during the sampling period is associated with processes like adsorption and desorption of phosphate and buffering action of sediment under varying environmental conditions according to Rajasegar (2003). The mean concentration of phosphorus recorded in Lake Solai was higher than the maximum value expected for natural unpolluted waters (0.090 mg L^{-1}) (Chapman and WHO, 1996). Most values of total phosphorus recorded during the sampling period indicated that of eutrophic water body (> 0.035 mg L^{-1}) (OECD, 1982).

Phytoplankton community structure

The phytoplankton community structure in Lake Solai revealed that Cyanobacteria (blue-green algae) was the most dominant of the algal groups during the study period. It dominated both the biovolume and cell density of the lake. The Cyanobacteria dominance has been reported in lakes Nakuru, Oloiden and Elementaita (Okoth, 2009; Kalff and Watson, 1986).The peak dominance period of Cyanobacteria in Lake Solai was in June. During this month, there was very high turbidity and high amounts of total suspended solids that may have led to low light penetration. Cyanobacteria being shade tolerant and able to adjust their vertical position in water were able to come to the surface and continue photosynthesizing at the disadvantage of the other algal groups. The presence of high levels of nutrients especially nitrogen and phosphate in a generally turbid lake with high temperatures as is the case with Lake Solai, encourages the dominance of the Cyanobacteria. As pointed out by Reynolds (1984), high temperature, low secchi depth, high turbidity and high phosphorus levels support the dominance of Cyanobacteria species. Occassional dominance by *Microcystis* and *Anabaena* has also been reported in Lake Victoria (Sitoki *et al.*, 2012). Dominance of *Microcystis* in Lake Solai can be attributed to the large colonies formed by the *Microcystis* sp, which enhances buoyancy enabling them to rise to the surface fast and benefit from the increased light intensity (Sitoki *et al.*, 2012). The presence of known toxin producing species of Cyanobacteria poses a health risk to livestock and humans that use the lake water directly , this is because they produce toxins

(Haande *et al.*, 2007; Pinckney *et al.*, 2001), although toxicity will depend on the type of Cyanobacteria present (Smith, 2003).

The presence of the three species (*Euglena* sp., *Phacus* sp. and *Trachelomonas* sp.) of Euglenophyta could be an indication of organic pollution since they are mostly common in waters rich in decaying organic matter. According to Kumar (2006) and Laskar (2009), the presence of Euglenophyta in a water body is an indication of organic pollution. Although the Chlorophyta is the second largest and important group of fresh water green algae (George *et al.*, 2013), it was the third most dominant group during the sampling period in Lake Solai. The Chlorophyta group in Lake Solai was dominated by the *Chlorella* sp., which was present throughout the sampling period. This is because *Chlorella* sp. can use different sources of nitrogen (NO_3 –N, NH_4 -N, NO_2 –N and even Urea) which were present in relatively high amounts in Lake Solai. The ability of *Chlorella* sp. to use the different forms of Nitrogen has been reported by De Lourdes (2017). The high phosphorus content as is the case in Lake Solai also favours the prevalence of *Chlorella* sp. This is according to Reynolds (1998) who suggested that *Chlorella* sp. is able to thrive in a habitat with relatively rich phosphorus content. Although Bacillariophyta is the most dominant group among phytoplankton, it was poorly represented throughout the sampling period in Lake Solai. This is associated with absence of random natural mixing to suspend and maintain the cells in the water column and reduced light penetration into the lake due to high turbidity values that selects against most of the other phytoplankton groups in favor of Cyanobacteria that inhabit such a niche.

The Chrysophyta was poorly represented throughout the sampling period. This is attributed to the fact that Chrysophyta prefer oligotrophic conditions (Kalff andWatson, 1986), hence the eutrophic conditions of Lake Solai was a limitation to the Chrysophyta. Chrysophyta prefer low phosphorus levels (< 20 µg L^{-1}) and specific electrical conductivities (50 µ Scm^{-1}) (Sandgren, 1986). However, the phosphorus levels (2.85 to 20.03 mg L^{-1}) and the conductivity (1461.78 to 2685.5 µS cm^{-1}) in Lake Solai was far greater than this preference hence limiting their presence.

Nitrogen and phosphorus are the most important nutrients for maintaining the growth and reproduction of phytoplankton (Jiang *et al.*, 2014). The high values of nitrate-nitrogen and phosphorus levels recorded during the study period showed that these nutrients were not limiting factors to the phytoplankton. However, there was low species diversity recorded in Lake Solai. This could be attributed to the high turbidity and total suspended solids recorded during the study period that caused light limitation giving a competitive advantage to few species. According to the different species of phytoplankton present, Lake Solai can be said to be eutrophic.

Conclusion

Lake Solai is a turbid moderately saline and eutrophic lake. Its high turbidity is an impediment to the life of most aquatic biota and is responsible for its low biodiversity. Owing to the dominance of Cyanobacteria in the lake waters and in particular the presence of toxin producing species like *Microcystis*, this water may not be suitable for domestic use. However, the levels of oxygen were within the permissible limits recommended for fisheries and aquatic life. Hence, the possibility of introducing salt tolerant fish should be explored.

Acknowledgment

We thank Egerton University through the Biological Sciences Department and the Kenya Marine and Fisheries institute (KMFRI) for granting us access to their laboratory and assistance in phytoplankton analysis.

References

- ✓ APHA (2005) Standard Methods for the Analysis of Water and Wastewater. American Public Health Association and Water Pollution Control Federation. 25th ed. Washington DC.
- ✓ Chapman D.V. and World Health Organization (1996) Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. E & F N Spon Ltd., Londen
- ✓ De Bock T., Kervyn de Meerendré B., Hess T., and Gouder de Beauregard A.C. (2009) Ecohydrology of a seasonal wetland in the Rift Valley: ecological characterization of Lake Solai. African journal of ecology, 47: 289-298.
- ✓ De Lourdes F.M., Josefina, R.R.M.D., Ulises M.M.C. and de Jesús M.R.A. (2017). Tolerance and nutrients consumption of Chlorella vulgaris growing in mineral medium and real wastewater under laboratory conditions. Open Agriculture, 2: 394-400.
- ✓ Dhanam S., Sathya A. and Elayaraj B. (2016) Study of physico-chemical parameters and phytoplankton diversity of Ousteri Lake in Puducherry. World Scientific News, 54: 153-164.
- ✓ EPA (2001) Parameters of Water Quality: Interpretation

and Standards. Environmental Protection Agency, Wexford.
- Fathi A.A. and Flower R.J. (2005) Water quality and phytoplankton communities in Lake Qarun (Egypt). Aquatic Sciences, 67: 350-362.
- Goman M., Ashley G.M., Owen R.B., Hover V.C. and Maharjan D.K. (2017) Late Holocene Environmental Reconstructions from Lake Solai, Kenya. The Professional Geographer, 69: 438-454.
- Gupta V.K. and Rastogi A. (2008) Biosorption of lead from aqueous solutions by green algae Spirogyra species: kinetics and equilibrium studies. Journal of hazardous materials, 152: 407-414.
- Haande S., Ballot A., Rohrlack T., Fastner J., Wiedner C. and Edvardsen B. (2007) Diversity of Microcystis aeruginosa isolates (Chroococcales, Cyanobacteria) from East-African water bodies. Archives of Microbiology, 188: 15-25.
- Hillebrand H., Dürselen C.D., Kirschtel D., Pollingher U. and Zohary T. (1999) Biovolume calculation for pelagic and benthic microalgae. Journal of phycology, 35: 403-424.
- Irfanullah H.M. (2006) Algal taxonomy in limnology: an example of the declining trend of taxonomic studies. Hydrobiologia, 559: 1-9.
- Jiang Y.J., He W., Liu W.X., Qin N., Ouyang H.L., Wang Q.M. and Xu F.L. (2014) The seasonal and spatial variations of phytoplankton community and their correlation with environmental factors in a large eutrophic Chinese lake (Lake Chaohu). Ecological Indicators, 40: 58-67.
- Johnson L.R. (2002) The freshwater algal flora of the British Isles: an identification guide to freshwater and terrestrial algae. Cambridge University Press, Cambridge.
- Kervyn de Meerendre B. (2004) Impact assessment of agricultural practices on water resources in the Lake Solai catchment (Kenya). Master's thesis, Cranfield University, Silsoe, UK.
- Kiage L.M., Liu K.B., Walker N.D., Lam N. and Huh O.K. (2007) Recent land-cover/use change associated with land degradation in the Lake Baringo catchment, Kenya, East Africa: evidence from Landsat TM and ETM+. International Journal of Remote Sensing, 28: 4285-4309.
- Kotut K., Njuguna S.G., Muthuri F.M. and Krienitz L. (1999) The physico-chemical conditions of Turkwel Gorge Reservoir, a new man-made lake in Northern Kenya. Limnologica, 29: 377-392.
- Laskar H.S. and Gupta S. (2009) Phytoplankton diversity and dynamics of Chatla floodplain lake, Barak Valley, Assam, North East India–a seasonal study. Journal of Environmental Biology, 30: 1007-1012.
- Lund H.C. and Lund J.W.G. (1995) Freshwater Algae Their Microscopic World Explored. Biopress Ltd., Londen.
- Manjare S.A., Vhanalakar S.A. and Muley D.V. (2010) Analysis of water quality using physicochemical parameters Tamdalge tank in Kolhapur district, Maharashtra. International Journal of Advanced Biotechnology and Research, 1: 115-119.
- Manohar S., Kitur E. and Kibet F. (2016) Water Quality and Plant Species Composition of Selected Sites within Chemususudam, Baringo County, Kenya. Journal of Environmental and Analytical Toxicology, 6: 6-11.
- Melack J.M. (1988) Primary producer dynamics associated with evaporative concentration in a shallow, equatorial soda lake (Lake Elementaita, Kenya). In: Melack (ed) Saline Lakes (pp. 1-14). Springer, Dordrecht.: 1-14.
- Oduor S.O., Schagerl M. and Mathooko J.M. (2003) On the limnology of Lake Baringo (Kenya): I. temporal physico-chemical dynamics. Hydrobiologia, 506: 121-127.
- Oduor S.O. and Schagerl M. (2007) Phytoplankton primary productivity characteristics in response to photosynthetically active radiation in three Kenyan Rift Valley saline-alkaline lakes. Journal of Plankton Research, 29: 1041-1050.
- Okoth O.E., Mucai M., Shivoga W.A., Miller S.N., Rasowo J., and Ngugi C.C. (2009) Spatial and seasonal variations in phytoplankton community structure in alkaline–saline Lake Nakuru, Kenya. Lakes and Reservoirs: Research and Management, 14: 57-69.
- Ongom, R., Andama, M., and Lukubye, B. (2017) Physico-Chemical Quality of Lake Kyoga at Selected Landing Sites and Anthropogenic Activities. Journal of Water Resource and Protection, 9: 1225-1243.
- Oniye S.L., Ega R.A., Ajanusi O.J. and Agbede R. (2002) Some aspects of the physicochemical parameters of Zaria Dam, Nigeria. Journal of Agriculture and Environment, 11: 367-379.
- Ouma H., and Mwamburi J. (2014) Spatial variations in nutrients and other physicochemical variables in the topographically closed lake baringo freshwater basin (kenya). Lakes and Reservoirs: Research and Management, 19: 11-23.
- Pinckney J.L., Paerl H.W., Tester P. and Richardson T.L. (2001) The role of nutrient loading and eutrophication in estuarine ecology. Environmental Health Perspectives, 109: 699 -706
- Rajasegar M. (2003) Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. Journal of Environmental Biology, 24: 95-101.
- Reynolds C.S. (1984) The ecology of freshwater phytoplankton. Cambridge University Press, Cambridge.
- Reynolds C.S. (1998) What factors influence the species composition of phytoplankton in lakes of different trophic status. Hydrobiologia, 369: 11-26.
- Sandgren, C. D., 1986. Effects of environmental temperature on the vegetative growth and sexual life history of *Dinobryon cylindricum* Imhof. In: Kristiansen and Andersen (eds.) Chrysophytes: Aspects and Problems, Cambridge Univ. Press, New York, USA.: 207-228.
- Sitoki L., Kurmayer R. and Rott E. (2012) Spatial variation of phytoplankton composition, biovolume, and resulting microcystin concentrations in the Nyanza Gulf (Lake Victoria, Kenya). Hydrobiologia, 691: 109-122.
- Smith V.H. (2003) Eutrophication of freshwater and coastal marine ecosystems a global problem. Environmental Science and Pollution Research, 10: 126-139.
- Symader W. and Bierl R. (1998) The heterogeneity of runoff and its significance for water quality problems.

Hydrological sciences journal, 43: 103-113.
- Talling J.F. (1989) The phytoplankton of Lake Victoria (East Africa). Archiv für Hydrobiologie. Beihefte. Ergebnisse der Limnologie, 25: 229-256.
- Tomas C.R. (1997) Identifying marine diatoms and dinoflag-ellates. Marine Geology, 3: 320-321.
- Utermöhl H. (1958) Toward the improvement of the quantitative phytoplankton method. Mitteilungen-Internationale Vereiningung fur Limnologie, 9: 1-38.
- Vanitha M. and thatheyus J.A. (2016) Physicochemical Characteristics and Plankton Assemblages of Sathiyar River in Madurai District. Scirea Journal of Agriculture, 1: 118-123.
- Vijayakumar S., Rajesh K.M., Mendon M.R. and Hariharan V. (2000) Seasonal distribution and behaviour of nutrients with reference to tidal rhythm in the Mulki estuary, Southwest coast of India. Journal of Marine Biology Assessment of India, 42: 21-31.
- Varadharajan D., and Soundarapandian P. (2014) Effect of physico-chemical parameters on species biodiversity with special reference to the phytoplankton from Muthupettai, South East Coast of India. Journal of Earth Science and Climatic Change, 5: 5 doi 10.417/2157-7617.1000200.
- Wetzel R.G. (2001) Limnology: lake and river ecosystems. Third Edition, Academic Press, San Diego.
- Wetzel R.G. and Likens G.E. (2013) Limnological analyses. springer-verlag, New York.

Zafar F.H. S., Ayub Z., Karim A., Zahid M., and Bat L. (2018) Seasonal variations in physico-chemical parameters of Buleji and Paradise Point rocky shores at Karachi coast. International Journal of Environment and Geoin-formatics, 5: 154-168.