

Physical-chemical water parameters structuring phytoplankton assemblages in endorheic and alkaline lentic system, Lake Rukwa in the Western Rift Valley, Southern Highlands of Tanzania

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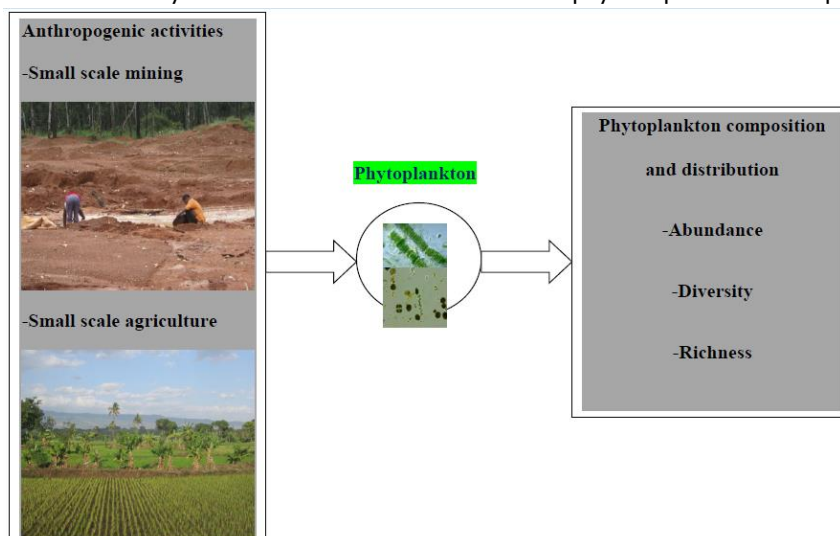
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Lake Rukwa is the only endorheic and alkaline lentic system in the Western Rift Valley, in the Southern Highlands of Tanzania. Due to anthropogenic impacts threatening this system, there is a need to understand various factors and processes affecting its phytoplankton community. Phytoplankton were studied in three locations, one offshore (zone 1) and two near river Luika (zone 2) and Songwe (zone 3) in the dry and wet seasons (October 2016 and May 2017), respectively. The study examined the composition, distribution and assemblage structure of phytoplankton in relation to physical water parameters. A total of 19 species belonging to four classes were recorded. These included nine species of Bacillariophyceae (Diatoms), four species of Dinoflagellates, three species of Cyanobacteria and three species of Chlorophytes. The sampling zones differed significantly in phytoplankton composition and richness, with richness being high in offshore open waters than in the river mouths. Spearman's rank correlation between water parameters and phytoplankton community attributes indicated the influence of physical parameters on phytoplankton distribution.



Keywords: Phytoplankton, Composition, Abundance, Freshwater, Lake Rukwa.

Introduction

Lake Rukwa is the only endorheic and alkaline lentic system in the Western Rift Valley, southern highlands of Tanzania (Haberyan, 1987; WREM, 2013). It is characterized by substantial diversity of species, habitats and by the presence of endemic, rare, and threatened species of fauna and flora (WREM, 2013). Lake Rukwa is one of the most biologically productive ecosystems in the country. It supports various aquatic organisms including freshwater turtles, hippopotamus, crocodiles, fish, various macroinvertebrates and plankton (Ricardo, 1936; Haberyan, 1987). While the lake is still in a relatively pristine state, it is facing many threats including those related to climate change and anthropogenic disturbances from surrounding environments such as mining, livestock keeping and agricultural activities.

Due to inadequate monitoring facilities, limited availability of quality data and accessibility to the lake, little is known about Lake Rukwa. Limited studies has been conducted in Lake Rukwa and most of them relied particularly on water quality. Biological studies focusing on phytoplankton and zooplankton are scanty (reference).

Phytoplankton are essential organisms which contribute to the primary food supply in any aquatic ecosystem. They are the initial biological components from which energy is transferred to higher organisms through food chain (Tiwari and Chauhan, 2006;

Saifullah et al., 2014). Physicochemical parameters are the major factors that control the dynamics and structure of the phytoplankton community in any aquatic ecosystem (Hulyal and Kaliwal, 2009). Seasonal variations in these parameters play an important role in the distribution, periodicity, quantitative and qualitative composition of freshwater biota. Thus, knowledge of the physical, chemical and biological characteristics of impacted ecosystems is extremely important (Xavier, 2005).

Several studies on phytoplankton of the Rift Valley soda lakes in East Africa have been conducted in the Eastern Rift Valley with little attention paid to the Western Rift Valley. Those studies include ones at alkaline endorheic Kenyan Rift Valley Lakes such as Bogoria, Nakuru and Elmentaita (Odour and Schagerl, 2008), and alkaline Tanzania lakes including Big Momela, Manyara and Embakai (Kihwele and Moronda, 2004; Lugomela et al., 2006; Kaaya, 2007). However, no study has been conducted on the relationship between physical-chemical water parameters and phytoplankton composition in the Western Rift Valley, particularly Lake Rukwa in Southern highlands of Tanzania. Therefore, the present study was aimed at determining the influence of physical water parameters on phytoplankton composition and distribution in Lake Rukwa, which is vulnerable to anthropogenic pressures. An understanding of the phytoplankton communities over time might help in management and preservation of this fragile habitat.

Materials and Methods

Description of the study site

Lake Rukwa is the fourth largest lake in Tanzania located on the south western regions of Rukwa, Katavi and Songwe at 8000'S 32025'E and 8.000°32.417°E. It is within the Great Rift Valley system. The lake covers an area of about 29,219 square kilometers and lies between Lake Tanganyika and Nyasa (also known as Lake Malawi). The alkaline Lake Rukwa lies at an elevation of about 800 metres (Lake Rukwa Basin Report, 2015). The lake has a large floodplain, and its size varies depending on the amount of rain that falls during rainy season and the water from the inflowing rivers. The Rungwa River flows into the lake from the north, while the Momba River flows from the Western area (WREM, 2013). Three other large inflows come in from the south, namely, the Lupa, Chambua and Songwe Rivers. Although there are many rivers flowing in, Lake Rukwa doesn't have any outlets. The northern part of the basin is often dry, whilst the western area is shallow. The southern basin is deeper, with an average depth of 4-6 meters, with a maximum depth of 15 meters. A population of about 2.2 million (Census, 2002) relies on Lake Rukwa for various economic activities such as fishing, livestock keeping, agriculture and mining. The lake is surrounded by numerous *Typha* species and mountainous trees.

Lake Rukwa is situated in a tropical, wet miombo woodland climatic region. The annual rainfall starts in November through May, contributing to increment of water level in the lake. In the southern part of the reservoir the annual average rainfall is about 650 millimeters, while in the northern it is 900 millimeters. The average surface temperature of the lake is between 20 and 35 degrees Celsius. The study area was divided into three zones open waters; Luika River mouth and Songwe River mouth (Fig. 1). Description of the sampling zones is provided in Table 1.

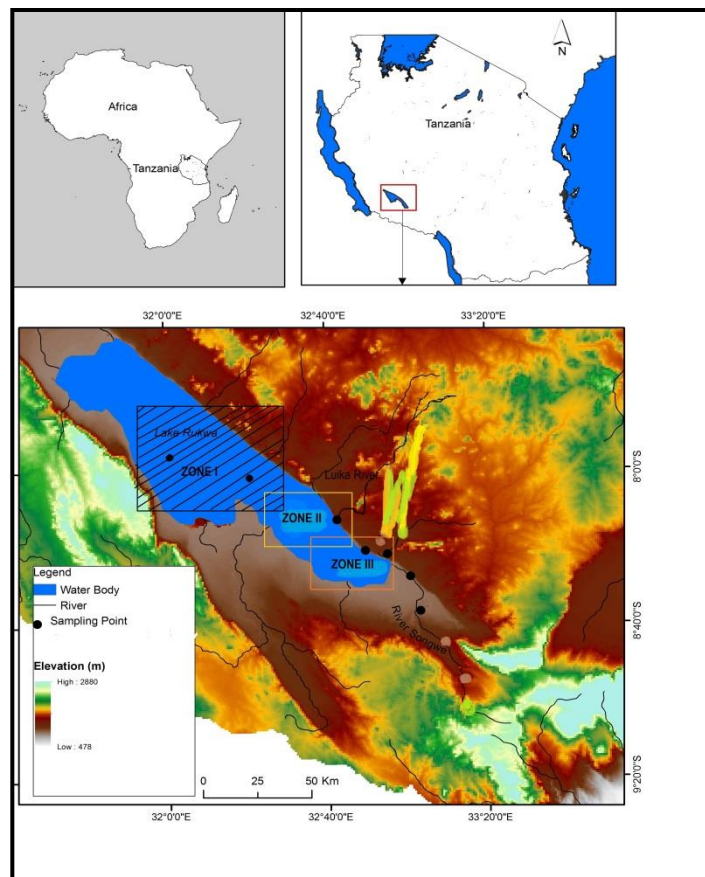


Fig. 1. Map of the Lake Rukwa, showing locations of sampling zones.

Table 1. Seasonal variations in physical water characteristics of Lake Rukwa in October, 2016 and May, 2017 with one way ANOVA.

Parameter/Season	Dry	Wet	ANOVA F-ratio
pH	9.22	8.50	0.29
Temperature (°C)	28.98 ± 1.90	26.40 ± 0.55	33.30*
Conductivity(μScm ⁻¹)	2200 ± 1.35	2000.0 ± 0.65	38.90*
Turbidity (NTU)	70.2 ± 0.35	120.0 ± 0.55	0.75

* $p < 0.05$

Sampling design

Triplicate samples of water quality parameters and phytoplankton were collected in each Zone, covering part of the dry season (October 2016) and part of the wet season (May 2017).

Water samples were collected simultaneously from the same sections that were sampled for phytoplankton and were analysed for physical chemical characteristics. Water quality parameters including pH, conductivity and temperature were recorded *in situ*. Temperature (°C), and conductivity (μS cm⁻¹) were measured using a hand held refractometer (Model YSI #85/10 FT, USA) while pH was measured using a hand held pH/mV meter (Saxin Model SX 711).

Phytoplankton sampling

The phytoplankton samples were collected during the day between 11.00-14.00 hr by towing a 20 μm mesh size Hydrobios plankton net using a motorized 25 Hp engine boat driven at low speed below the water surface (at a depth of 0.5 m for 5 minutes). Collected samples were immediately transferred to a 250 ml labelled brown glass bottle. Ten samples were collected from each zone, preserved in Lugol's solution prior to microscopic analysis (Yig'it, 2006; Kolo et al., 2010). In the laboratory phytoplankton species were identified by using light microscope at different magnifications (10 X, 40 X and 100 X) and identified using identification keys such as Barber and Haworth (1981); Bellingier, (1992) and Janse Van Vuuren et al. (2006).

Phytoplankton community structure was analysed using three univariate indices (Shannon-Wiener diversity index, Margalef richness index and Pielou's evenness index) to express the degree of uniformity in the distribution of individuals among taxa in the study area (Imoobe and Adeyinka, 2009).

Statistical analysis

All measured physical parameters, except for pH, were expressed as means ± SE for each sampling station; pH was expressed as median. Phytoplankton abundance data were transformed (using log ($x + 1$)) to meet the statistical criteria for normality. One-way analysis of variance was used for data analysis. Duncan's multiple range test (DMRT) (Zar, 2001) was done to determine the difference between sampling stations and seasons. Relationships between physical-chemical water quality parameters with diversity indices were determined by a Pearson's rank correlation test.

Results

Physical parameters

Conductivity and temperature, showed significant variation in both space and time ($p < 0.05$) whereas pH values varied significantly ($p < 0.05$) temporally, but not spatially (Tables 2 and 3, Fig. 2). Conductivity varied significantly between zones ($p < 0.05$). There was a general decline in conductivity over time. The lowest temperature was recorded at Zone II and III and this showed significant difference ($p < 0.05$) from zone I. The highest temperature was recorded in October 2016 and the lowest in May, 2017. The highest pH value was recorded in May 2017 and the lowest in October 2016.

Table 2. Composition, Distribution and relative abundance of phytoplankton species in endorheic Lake Rukwa study Zones (I - III), Tanzania.

Taxa	Species	Zone I number/ml	Zone II number/ml	Zone III number/ml	Mean number/ml
Bacillariophyceae	<i>Coscinodiscus sp</i>	1578 (92.22%)	50 (2.92%)	83 (5.85%)	570
	<i>Thalassiosira sp</i>	389 (100%)	0.00	0.00	130
	<i>Cyclotella sp</i>	720 (80.17%)	90 (10.02%)	88 (9.79%)	299
	<i>Stephanodiscus sp</i>	640 (90.90%)	64 (9.09%)	0.00	235
	<i>Cyclostephanus sp</i>	430 (88.84%)	54 (11.15%)	0.00	161
	<i>Aulacoseira sp</i>	325 (100%)	0.00	0.00	108
	<i>Lauderia sp</i>	400 (100%)	0	0	133
	<i>Skeletonema sp</i>	280 (80.92%)	34 (9.82%)	32 (9.24%)	115
	<i>Navicula sp</i>	310 (76.16%)	44 (10.81%)	53 (13.02%)	136
Dinophyceae	<i>Prorocentrum spp</i>	1052 (74.71%)	246 (17.47%)	110 (7.81%)	469
	<i>Diplopsalis sp</i>	1350 (100%)	0	0	450
	<i>Dinophysis sp</i>	980 (91.58%)	90 (8.41%)	0	357
	<i>Peridinium sp</i>	826 (86.40%)	0	130 (13.59%)	318
Cyanophyceae	<i>Anabaena sp</i>	640 (100%)	0	0	213
	<i>Microcystis sp</i>	648 (100%)	0	0	216

	<i>Chroococcus sp</i>	280 (50%)	160 (28.57%)	120 (21.42%)	187
Chlorophyceae	<i>Pediastrum sp</i>	157 (90.75%)	16 (9.24%)	0	58
	<i>Monoraphidium sp</i>	253 (99.21%)	0	2 (0.78%)	85
	<i>Carteria sp</i>	78 (84.78%)	8 (8.69%)	6 (6.52%)	31
Total		11336	856	624	4272

*Values in parenthesis are percentages of relative abundance (%) of phytoplankton species.
*Values are rated across zones on species basis.

Table 3. Community attributes of phytoplankton communities in Endorheic Lake Rukwa study Zones (I-III) in October, 2016 and May, 2017.

Indices	Zone I	Zone II	Zone III	ANOVA F-ratio
Total number of species	19	17	16	-
Total number of Individuals	11336	856	624	-
Shannon-Wiener Index	3.201	2.872	2.890	23.56*
Pielou Evenness Index	0.829	0.751	0.747	45.79*
Margalef Richness Index	3.192	3.150	3.091	13.89*

* $p < 0.05$.

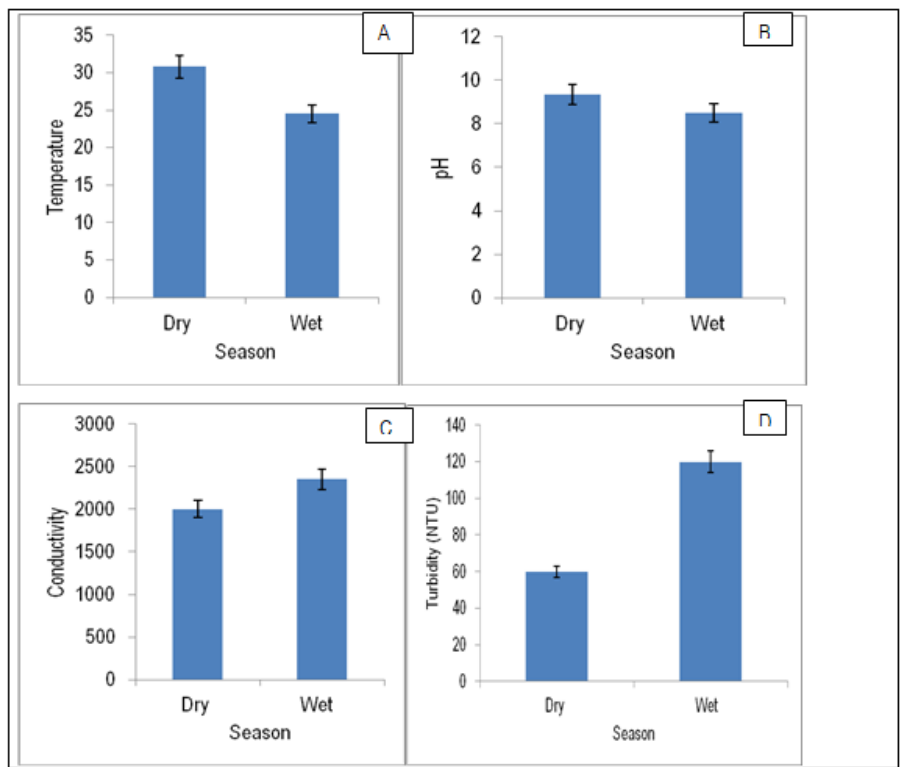


Fig. 2. Seasonal variations of physical parameters (mean \pm SE) and median pH of the study area: A) temperature ($^{\circ}$ C); B) pH; C) Conductivity (μ S cm^{-1}); D) Turbidity (NTU).

Phytoplankton assemblages

Four classes of phytoplankton comprising of 19 species were identified during the study. These included nine species of diatoms, four species of dinoflagellates, three species of cyanobacteria and three species of chlorophytes. Some species were found in all zones while others were not observed in some zones. Species richness was greatest in Zone I, while few species were found only in Zones II and III.

There were significant differences ($p < 0.05$) among seasons in the diversity indices, as evidenced by the ANOVA. There were differences in abundance between zones and the sampling periods ($p < 0.05$). Zone I had the highest mean abundance per sample (390.7 ± 73.9), whereas zone III had the lowest (98.5 ± 29.4) (Fig. 3). With respect to temporal variation in abundance, October, 2016 had lower mean abundances compared to May, 2017 (Fig. 4).

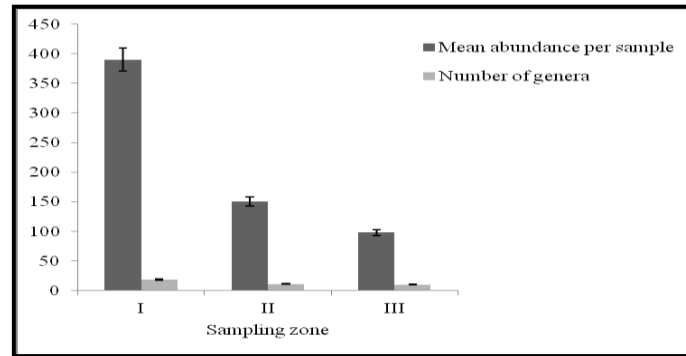


Fig. 3. Spatial variation in mean (\pm SE) abundance and number of phytoplankton genera among Lake Rukwa sampling zones.

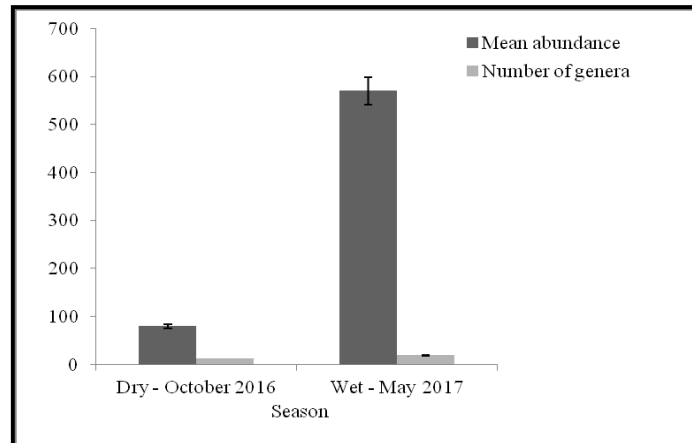


Fig. 4. Temporal variation in mean (\pm SE) abundance and number of phytoplankton genera in the endorheic Lake Rukwa.

In all, the diatoms species, *Coscinodiscus sp*, *Cyclotella sp*, and *Navicula sp* were respectively found dominant in Zone I (92.22%), Zone II (10.02%), and Zone III (13.02%), while *Navicula sp*, *Coscinodiscus sp* and *Coscinodiscus sp* had the least relative abundance in Zones I (76.16%), II (2.92%) and III (5.85%), respectively. In the class Bacillariophyceae, the species with the maximum and minimum number of individuals were *Coscinodiscus sp* (570 individuals/ml) and *Aulacoseira sp* (108 individuals/ml), respectively. Only one genera of the class Dinophyceae (*Prorocentrum spp*) was recorded in high numbers in Zone II (17.47%) and had the lowest number in Zone III (7.81%).

In the class Cyanophyceae, three genera (Anabaena, Microcystis, Chroococcus) were recorded in Zone I while only Chroococcus was recorded in Zones II and III. In Zone I Anabaena and Microcystis had the highest relative abundance (100%) each. Chroococcus had the least relative abundance (50%) of genera in this class.

Three genera of the class Chlorophyceae were recorded in this study across the three sampling zones. Carteria, was dominant in Zone III followed by Pediastrum in Zone II and Monoraphidium in Zone I, with each having a relative abundance of 6.52%, 9.24% and 99.21%, respectively.

Phytoplankton species diversity and richness indices

the value of species diversity, richness and evenness indices of phytoplankton in the study area. Shannon-Wiener index, Margalef richness index and Pielou's evenness index for phytoplankton were 3.201, 3.192 and 0.829 respectively in zone I. 2.872, 3.150 and 0.751 respectively in zone II and 2.890, 3.091 and 0.747 respectively in zone III.

Relationship between physical chemical parameters, phytoplankton abundance and community attributes

Spearman's rank correlation was performed to assess the relation between physical parameters and phytoplankton community attributes. Abundance correlated positively with most of the physical-chemical water quality parameters except for turbidity and conductivity. Phytoplankton abundance was lowest during the dry period (October). It increased progressively with the onset of the rainy season, but started to decline during peak flows in May. During this period Luika and Songwe Rivers were characterized by large quantities of suspended matter, turbid water and high sediment loads. There was significant negative correlation between turbidity, conductivity and phytoplankton diversity.

Discussion

Four taxonomic groups of phytoplankton were identified in this study and each group was widely distributed in all the sampling zones. However, diatoms dominated the species identified, followed by dinoflagellates, cyanobacteria and chlorophytes. Similar high dominance of diatoms was reported by Oduor and Schagerl, 2008 in the saline, alkaline endorheic Kenyan Rift Valley lakes i.e. Bogoria, Nakuru and Elementaita. In contrast, it disagrees with the study by Lugomela et al. (2006) in three alkaline lakes of Big Momela, Manyara and Embakai, Tanzania where cyanobacteria dominated the phytoplankton taxa. Phytoplankton variation in Lake Rukwa likely reflects environmental and seasonal differences. The species richness in Rukwa was greater than the 10 species

reported by Kihwele and Moronda (2004) from Lake Manyara, but it is less than the 20 species reported by Lugomela et al. (2006) in the Lake Big Momela. Phytoplankton species identified in this study are typical of the Rift Valley soda Lakes in East Africa. According to Oduor and Schagerl (2008) earlier reported the most dominant phytoplankton species in East African freshwater ecosystems are diatoms, cyanobacteria, dinoflagellates and chlorophytes.

According to Jakhar (2013), the phytoplankton community composition in any particular aquatic habitat usually provide information on the prevailing and existing physical and chemical conditions of that habitat. Therefore, the interaction between various physical-chemical water quality parameters can either favour the growth or mortality of phytoplankton, both spatially and seasonally (Yakubu et al., 2000). Phytoplankton have been identified as bio-indicators of aquatic environmental perturbation (Abowei and Sikoki, 2005) because of their easy identification during their period of high density, and high sensitivity to aquatic environmental change compared to other aquatic fauna. Furthermore, the diversity, abundance and seasonality of different phytoplankton groups in aquatic ecosystem affect different biotic components therein, giving them substantial potential in assessing aquatic ecosystem health.

In this study, temporal differences in taxon richness and abundance were recorded between the dry and rainy seasons. Low taxon richness was recorded during the dry period and at the onset of the rains and a significant reduction in abundance was recorded during the peak of rainy season. This finding was in line with those of other studies in saline, alkaline Rift Valley Lakes in East Africa, where phytoplankton abundance was highest at the onset of the rains and declined progressively as the rainfall increased (Kihwele and Moronda 2004; Oduor and Schagerl 2008).

Dry conditions frequently lead to intolerable thermal stress and/or low dissolved oxygen levels for phytoplankton (Nassar, 2000 and Boyce et al., 2010). This could explain the temporal and spatial variation in taxon richness, composition and abundance of phytoplankton in the study area. Sharma et al. (2007) also reported high density of phytoplankton during rainy season in Chandrabhaga River, Garhwal the Himalayas. The environmental health of a particular aquatic ecosystem depends upon spatial-temporal distribution, species composition, relative abundance and biomass of phytoplankton (Khattak et al., 2005). In the present study the phytoplankton abundance showed similar trend between different zones while phytoplankton compositions did not show a trend. This may be due to variations in water quality between different seasons (Patrick, 1977).

Oduor and Schagerl (2008) reported the prevalence of cyanobacterium species *Arthrospira fusiformis* in Lake Bogoria as indicator of eutrophic condition in aquatic systems. Furthermore, the occurrence of cyanobacterium *Arthrospira fusiformis* in Lake Manyara indicated high level organic pollution as a result of high organic matter deposit (Kihwele and Moronda, 2004; Lugomela et al. 2006).

The diversity of phytoplankton species in soda lakes is inversely proportional to its abundance (Lugomela et al. 2006; Kaaya, 2007). The high diversity index recorded in Zone I compared to Zones II and III reflected the abundance of phytoplankton in the offshore areas of Lake Rukwa area than in the Luika and Songwe River mouths. High diversity index reported in Lake Manyara of Tanzania was linked to environmental parameters including temperature, light, nutrient availability, salinity, and pH (Lugomela et al, 2006; Kaaya, 2007). However, such high diversity may suggest larger food chain, inter-specific interaction and stability among the soda lake phytoplankton community.

Various studies on phytoplankton of the Rift Valley soda lakes in East Africa such as Nakuru, Bogoria, Elmenteita, Manyara, Natron and Momela reported that the phytoplankton communities in tropical alkaline saline lakes are often enhanced by high nutrient concentrations such as phosphorus and nitrogen, coupled with higher temperature, radiation, abrupt pH variation and salinity (Lugomela et al., 2006; Kaaya, 2007; Oduor and Schagerl, 2008). The dynamics of phytoplankton reflect the function of many environmental factors such as temperature, light, nutrient availability, salinity, pH, and mortality (Chalinda et al., 2004; Kaaya, 2007). In the present study, the composition and abundance of phytoplankton in Lake Rukwa waters were found to vary markedly due to the seasonal environmental fluctuations. It was observed that contribution of each group of phytoplankton in terms of abundance and composition was in the following order: Diatoms>Dinoflagellates>Cyanobacteria>Chlorophytes. High abundance of diatoms and dinoflagellates, in Lake Rukwa waters was due to the predominance period. Some genera occurred during both seasons (dry and wet) including; *Thalassiosira*, *Cymbella*, *Cyclotella*, *Stephanodiscus*, *Cyclostephanus* and *Prorocentrum* and were found in all zones although their numbers varied. The observed dominance of these genera is due to their preference of clear water as they are considered omnipresent in the lake waters (Sharma et al., 2007). The increased pH, high temperature and light penetration in Lake Rukwa during dry season, may have also contribute to the high abundance of diatoms and dinoflagellates.

In the current study, *Thalassiosira*, *Cymbella*, and *Prorocentrum*, were the most common genera to the other genera. Indeed, *Prorocentrum* and *Thalassiosira* are considered to be among the most common genera and are cosmopolitan in the tropics (Jain et al., 2007). Several species such as *Thalassiosira*, *Prorocentrum*, *Cyclotella*, *Stephanodiscus*, and *Cyclostephanos* species were found to occur in high numbers contributing substantially to the phytoplankton abundance. Their concentrations reported in this study were relatively higher than those of *Microcystis sp*, *Anabaena sp*, and *Monoraphidium sp*. This may suggest that the tropical waters of Lake Rukwa have high abundance of diatoms species, which may be due to physical-chemical water quality parameters. The low abundance of some phytoplankton in lake waters may also be due to grazing effect by zooplankton and viral infections, which are all well known to influence phytoplankton production in aquatic environment.

Other factors such as concentration of nutrients like nitrate, phosphate, and ammonium also play important roles both in phytoplankton growth and production (Yao et al., 2010). The species of phytoplankton observed in this study have been recorded in other East Africa freshwater lakes like Manyara, Victoria, Nyasa, Tanganyika, and Momela (Lugomela et al., 2006; Jain et al., 2007; Oduor and Schagerl, 2008).

Among the observed species some are potentially harmful blooming microalgae such as *Dinophysis*, *Microcystis*, and *Anabaena*. The competitive advantages of cyanobacteria in the lake may reduce the number of other phytoplankton species due to their ability to regulate their buoyancy and to fix atmospheric nitrogen which in turn add their allelopathic potentials and may further enhance their development even under low nutrient levels (Jacoby *et al.*, 2000; Singh and Balasingh, 2011). Thus when cyanobacteria blooms occur, illumination is reduced in the water column, reducing the growth of other producers that cannot maintain a position near the water surface as they cannot regulate buoyancy (Lugomela *et al.*, 2006).

Conclusion

This study has shown that phytoplankton community of Lake Rukwa is largely dominated by diatoms with *Cymbella* and *Cyclotella* being the most prominent genera. Others are cyanobacteria such as *Microcystis*, *Anabaena* and *Chroococcus*. These species should be given a special attention due to their ability to cause cyanotoxin pollution. More studies are required on the potential of harmful phytoplankton which produce cyanotoxin and others which pose threat to other living organisms. The abundance of phytoplankton in the Lake is a function of physical-chemical water quality parameters. The open water area favoured more diverse species of phytoplankton than other zones. The presence of some phytoplankton in the lake indicated that there was a high level of anthropogenic contamination in and around the water body. This therefore calls for urgent checks on the activities around the lake for sustainable ecosystem health and productivity.

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