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Recent limnological changes and their implication on fisheries in Lake Baringo, Kenya

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Water samples for physico-chemical analysis for this study were collected monthly for five years between April 2008 and March 2013. Conductivity, temperature, dissolved oxygen and pH was measured *in situ* using a Surveyor II model hydrolab. Chlorophyll-*a* concentration was determined using a Genesys 10S Vis spectrophotomer. Nutrients were determined using standard methods and procedures. Analysis of Variance (ANOVA) was used to determine spatial and temporal variation in physico-chemical and biological factors. Principal component analysis (PCA) was performed to establish the correlation of the physico-chemical and biological parameters among sampling stations and to group stations with similar physico-chemical parameters. Both spatial and temporal significant variations ($P < 0.05$) were detected in the concentrations of the nutrients measured during the study.

Key words: Limnological changes, parameters, Lake Baringo, Kenya.

INTRODUCTION

Lakes are said to be ephemeral features of the landscape. They show remarkable variability with time in their morphometry, physical, chemical and biological factors. Such variations are mainly induced by climatic changes and anthropogenic activities in the catchment area. In the last half of the 20th century there have been remarkable variations in climatic patterns, which have impacted negatively on the lake ecosystems (Ngaira, 2006). Such effects include frequent fluctuation in water levels, increased salinity and turbidity, among others. In the tropics, rainfall remains the major weather factor affecting the aquatic ecosystems in arid and semi-arid areas such as that of Lake Baringo. Lake Baringo in Kenya (East Africa) is a RAMSAR site, famous for its high bird diversity, hippopotamus and crocodile populations. The lake once supported a substantial fishery, and it also represents a precious source of fresh water in a semi arid area (Wahlberg et al., 2003). The lake has changed fundamentally in recent years; its ecosystem has become degraded and the fishery has dwindled. The deterioration is thought to be related to irrigation agriculture that reduces water inflow, and to excessive grazing by livestock in the lake catchment, which has led to increased erosion of soils (Bryan, 1994).

Lake Baringo is a highly variable system, governed primarily by changes in lake levels. These changes are

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well correlated with changes in water quality, lake vegetation, and in the composition of plankton community (Hakan et al., 2003). The lake is characterized by high turbidity caused by erosion of fine volcanic soils in the catchment. The sediment consists of fine silt and clay, which settle slowly and is easily re-suspended by wave action (Anon, 2003). The suspended solids influence the Secchi depth, euphotic zone and light attenuation coefficient. Turbidity indirectly affects the level of dissolved oxygen by limiting photosynthesis by reducing light penetration in water (Omondi et al., 2011).

Physical and chemical properties of any water body play a significant role in various aspects of hydrobiology. The interactions of physico-chemical properties of water have a significant role in the composition, distribution and abundance of aquatic organisms. It gives an insight into the relationship between organisms and their environment. Both physico-chemical properties and aquatic organisms are therefore used to determine the water quality and the structural composition of aquatic community (Sidneit et al., 1992). However these characteristics can be altered by anthropogenic activities in the lake as well as natural dynamics. The changes in physico-chemical properties affect water quality and quantity, species distribution and diversity, production capacity and causes ecological imbalance (Sidneit et al., 1992).

MATERIALS AND METHODS

Study area

Lake Baringo is a freshwater lake in the eastern arm of the Great Rift Valley in Kenya (Figure 1). It is located between latitude 0˚30' N and 0˚45' N and longitude 36° 00' E and 36° 10' E and lies approximately 60 Km north of the equator at an altitude of 975 m above sea level (Kallqvist, 1987). The lake has a surface area of approximately 130 Km^2 and a catchment of 6,820 Km^2. It has a mean depth of 3 m with the deepest point being about 7 m at high water levels.

Lake Baringo waters remain fresh despite lack of surface outlet, shallow depth and high net evaporation that characterizes the rift floor. Recent hydrogeological evidence confirms the original assumption (Beadle, 1932) that some lake water is lost by underground seepage through the fractured lake floor (Onyando et al., 2005). Dunkley et al. (1993) estimated that this outflow could exceed 108 m^3 $year^{-1}$. Lake Baringo has five islands, the biggest being the volcanic Kokwa. The island is a remnant of a small volcano that belongs petrogenetically to the Korosi volcano. This erupted during the Middle Pleistocene, approximately 2.6 million years ago (Cl'ement et al., 2003).

This area is characterized by dry and wet seasonality with unpredictable timing. The dry season usually starts from September to February while wet season occurs between March and August. Rainfall ranges from about 600 mm on the east and south of the lake to 1500 mm on the western escarpment of the Rift Valley. Lake Baringo experiences very high annual evaporation rates of 1650-2300 mm (Odada et al., 2006) and its survival depends on the inflows from rivers originating from the hilly basin where rainfall varies from 1100 to 2700 mm. The lake is fed by several seasonal rivers including Ol Arabel, Mukutan, Endao and Chemeron while Molo and Perkerra are perennial.

Global positioning system (GPS) navigational unit (Garmin II model) was used to locate the sampling stations. The stations S2, C2 and N2 lies on the South-North transect (Figure 1). Station S2 has the influence of rivers Molo and Perkerra. Station C2 is at the centre of the lake, while N2 lies in the north.

Sampling protocol

Samples were collected monthly for five years from April 2008 to March 2013. Depth was determined using a marked rope weighted at one end while a 20 cm diameter black and white Secchi disc was used to determine transparency. Turbidity was measured *in situ* using a HACH 2100P turbidimeter. 500 ml lake water samples for nutrients and chlorophyll *a* analyses were collected using a four litre Van Dorn sampler. These were kept in a cool box at 4°C and transported to the laboratory. In the laboratory, samples were filtered into 250 ml glass flasks using 0.45 µm pore size filter papers to remove phytoplankton before analysis.

Conductivity, temperature, dissolved oxygen and pH was measured *in situ* using a Surveyor II model hydrolab. The concentrations of ammonium nitrogen (NH_4-N) was analysed using the indophenol method while soluble reactive phosphorus (PO_4-P) was analysed using the ascorbic acid method. Nitrates nitrogen (NO_3-N) was determined by first reducing the nitrate-nitrogen to nitrite-nitrogen by passing the water sample through cadmium reduction column before adopting the sulfanilamide method to determine the nitrite-nitrogen concentrations. Silicate (SiO4) was determined by using the heteropoly blue method while Chlorophyll-*a* concentration was determined using a Genesys 10SVis spectrophotomer using acetone method (APHA, 2000).

Data analyses

Statistical computing language and environment R 2.15.0 (R Development Core Team, 2012) package was employed in data analyses and The R package ggplot2 (Wickham, 2009) was used for graphics. Analysis of Variance (ANOVA) was used in determining significant differences between spatial and temporal variation in physico-chemical and biological factors. Values with $\alpha < 0.05$ were considered significant. In cases where there were significant differences, Tukey's Multiple Range Test was used to separate the means. Principal Components Analysis (PCA) was performed to establish the correlation among the physico-chemical and biological parameters among sampling stations. Principal Components Analysis (PCA) was performed using PAST programme (Hammer et al., 2001) to establish the correlation of the physico-chemical and biological parameters among sampling stations and to group stations with similar physico-chemical parameters.

RESULTS

The mean (± SE) spatial values of physico-chemical factors measured during the study are shown in Table 1. The mean depth of the lake was 5.7 ± 0.30 m. Spatial values ranged from 5.2 to 6.2 m at S2 and N2, respectively. The depth increased from south to north of the lake. There were significant differences in depth among stations (F = 14.18, $P < 0.05$). Temporally the depth of the lake ranged from 2.95 in December 2009 to 9.55 m in September 2012 (Figure 2). There were significant differences in mean lake depth among months (F =350.22, $P < 0.05$). The spatial mean Secchi depth for

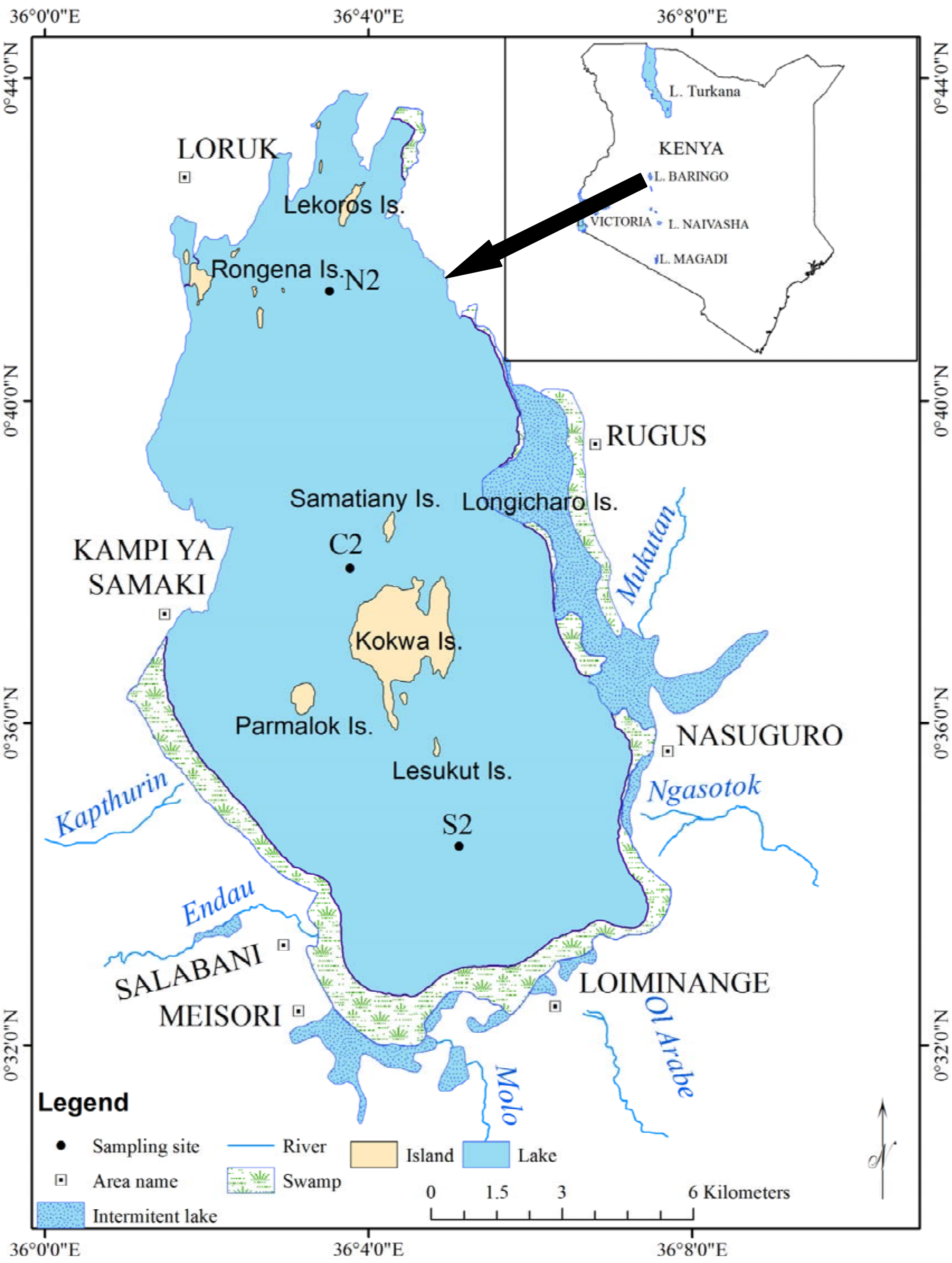

Figure 1. A map of Lake Baringo showing the stations, S2, C2, and N2, sampled during the study from April 2008 to March 2013.

the lake was 34.6 ± 1.4 cm. Values ranged from 32.0 to 36.8 cm at S2 and N2, respectively (Table 1). The mean spatial Secchi depths were not significantly different among stations (F = 1.82, $P > 0.05$).

Water transparency increased from south to north. Temporally, Secchi depth values ranged from 7 cm in March, 2010 to 146 cm in December, 2012. It was noted that the lowest Secchi depth coincided with the rainy season whereas the highest coincided with the dry season. There were significant variations in mean Secchi depth between months (F = 45.91, $P < 0.05$).

Turbidity of the lake ranged from 68.51 to 80.24 NTU at

Table 1. Mean (± SE) physico-chemical parameters and Chlorophyll *a* recorded at the sampling stations between April 2008 and March 2013.

Parameter	Station		
	C2	N2	S2
Alkalinity	199.93 ± 2.66	196.95 ± 3.10	199.20 ± 2.73
Chl a	12.27 ± 0.52	10.91 ± 0.51	13.84 ± 0.86
Conductivity	577.76 ± 9.47	581.97 ± 9.37	573.36 ± 10.02
Depth	5.98 ± 0.12	6.35 ± 0.12	5.31 ± 0.13
DO	6.73 ± 0.09	6.55 ± 0.08	5.93 ± 0.08
Hardness	68.86 ± 1.24	70.90 ± 3.51	69.33 ± 1.21
NH4	50.28 ± 2.44	47.57 ± 2.43	53.13 ± 4.88
pH	8.59 ± 0.42	8.51 ± 0.44	8.56 ± 0.42
Secchi	38.14 ± 1.90	40.24 ± 2.03	35.05 ± 1.87
Silicates	24.91 ± 0.37	25.58 ± 0.36	24.59 ± 0.36
SRP	32.99 ± 4.39	30.60 ± 4.27	39.23 ± 4.78
Temperature	26.68 ± 0.12	26.20 ± 0.13	24.84 ± 0.11
Turbidity	73.88 ± 3.89	68.58 ± 3.48	80.26 ± 4.26
Nitrates	8.13 ± 0.80	7.02 ± 0.72	11.29 ± 0.66
TDS	207.58 ± 3.8	215.78 ± 4.02	216.70 ± 4.34
Nitrites	3.60 ± 1.11	2.38 ± 0.66	5.30 ± 2.11
TP	104.32 ± 31.75	76.52 ± 20.57	99.56 ± 25.09
TN	1198.9 ± 219.88	1072.71 ± 220.9	1219.3 ± 191.15
TSS	12.44 ± 2.38	10.67 ± 1.89	13.78 ± 2.17

N2 and S2, respectively with a mean spatial turbidity of 74.24 ± 2.25 (Table 1). There were significant differences among stations (F= 2.26, $P > 0.05$). Tukey's Multiple Range test indicated significant differences in stations S2, C2 and N2. Turbidity decreased from south to north in the lake. The temporal turbidity ranged from 4.67 NTU in December, 2012 to 258 NTU in May, 2010. There were significant temporal differences (F = 7097.13, $P < 0.05$). The lowest turbidity coincided with the rainy season whereas the highest occurred in dry season. Spatial water temperatures ranged from 24.9 °C at S2 to 26.2°C at N2 with a mean temperature of 25.9 ± 0.77 °C. There was significant difference in the mean temperature between stations (F = 62.75, $P < 0.05$). Temporally temperature ranged from 22.1°C in May, 2010 to 31.8°C in August, 2008. There was significant difference in the mean temperature between months (F = 160.26, $P < 0.05$).

Dissolved oxygen concentration in the lake ranged between 5.89 mg l^{-1} and 6.7 mg L^{-1} at stations S2 and C2, respectively (Table 2) with a mean of 6.40 ± 0.05 mg L^{-1}. There was significant difference between the sampling stations (F = 25.79, $P < 0.05$). Further analysis showed that there were only significant difference in mean dissolved oxygen concentration in two pair of stations S2 and C2 ($P < 0.05$) and S2 and N2 ($P < 0.05$). Temporally, dissolved oxygen concentration ranged from 3 mg l^{-1} in February 2010 to 8.8 mg L^{-1} in March 2010. There were significant differences in the mean dissolved oxygen concentrations between the sampling months. (F = 81.03, $P < 0.05$). Spatially pH ranged from 7.2 at station N2 to 9.9 at station S2 while temporally this varied from 7.18 to 9.93 in September 2009 and March 2010, respectively. There was no significant difference between the sampling stations (F = 1.59, $P = 0.205$). Temporally there was no significant difference observed between the months (F = 0.86, $P > 0.05$).

Electrical conductivity values during the study fluctuated between 573.36 μ Scm^{-1} at S2 and 581.97 μScm^{-1} at N2, with a mean of 577.69 ± 5.55 μ Scm^{-1}. There was a decreasing trend in conductivity values from south to north. There was a significant difference in mean conductivity between sampling stations (F = 0.20, $P < 0.05$). Temporally conductivity values ranged from 486 μ Scm^{-1} to 867 μ Scm^{-1} in December, 2009 and April 2010, respectively. Significant difference was recorded in the mean conductivity between sampling months (F = 8420.59, $P < 0.05$). Both spatial and temporal significant variations were detected in the concentrations of the nutrients measured during the study (Figure 3). Between stations the highest concentrations of all the nutrients, except silicates, were realized at S2 with a decreasing trend from south to north. Ammonium concentrations fluctuated between 15.1 and 134.1 μg L^{-1}, nitrates between 2.1 and 15.3 μg L^{-1}, SRP from 4.5 to 73.4 μg L^{-1} and silicates from 22.4 to 33.6 mg l^{-1}.

Spatially, the amount of Chlorophyll *a* ranged from 11.91 at N2 to 13.8 4 μg L^{-1} at S2 with a mean of 12.4 ±

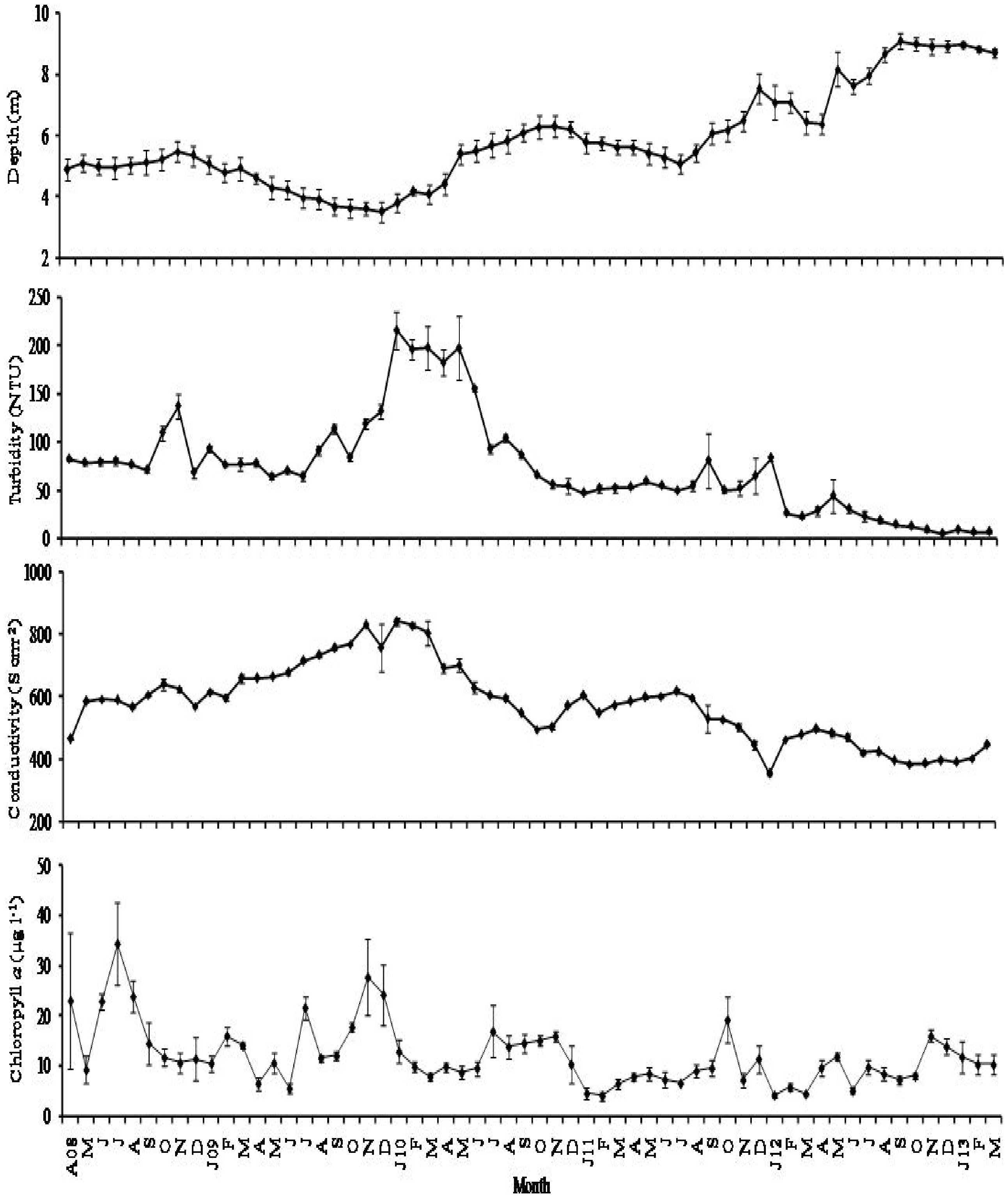

Figure 2. Monthly mean (± SE) of depth, turbidity, conductivity and chlorophyll *a* recorded at the sampling stations between April 2008 and March 2013.

0.8 µgL^{-1}. There was a significant difference in the mean Chlorophyll *a* concentration between stations (F = 4.79, *P* < 0.05). Temporally, Chlorophyll *a* concentration ranged from 2.6 µg L^{-1} in February, 2011 to 51 µg l^{-1} in July 2010

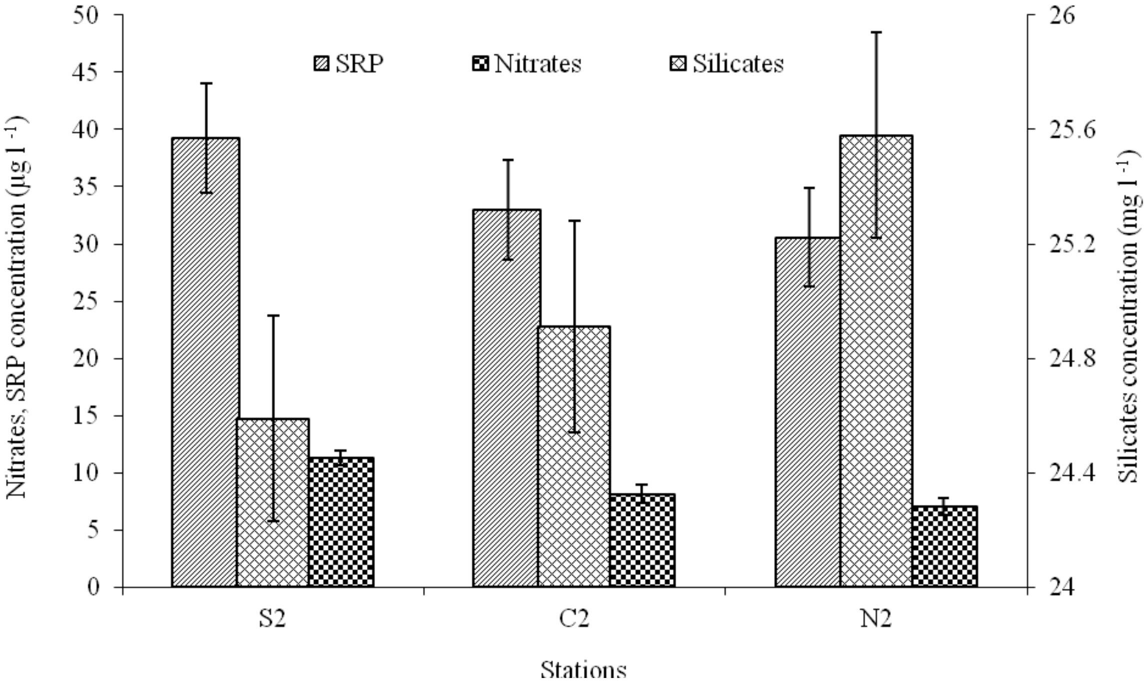

Figure 3. Spatial mean (± SE) of silicates, nitrates and SRP values recorded at the sampling stations between April 2008 and March 2013.

(Figure 2). There was also a significant difference in the mean Chlorophyll *a* concentration between the sampling months (F = 665.43, $P < 0.05$).

The PCA showed that the important environmental factors in the characterization of Station S2 are turbidity, nitrates, SRP, ammonium and Chlorophyll *a*. Sampling station C2 was characterized by alkalinity, dissolved oxygen and temperature while N2 was characterized by conductivity, hardness and silicates (Figure 4).

Euclidean clustering of the sampling stations based on the physico-chemical parameters showed that station S2 was separated from the other two stations (Figure 5).

DISCUSSION

The small difference in environmental variables across the sampling stations in the lake can be attributed to its small size and shallowness and also to the daily mixing of the lake water by wind action. Similar results have been reported for other lakes in the region (Burgis, 1971). Difficulty in establishing large-scale spatial heterogeneity in tropical lakes has also been attributed to their small size and shallowness (Sarma et al., 2005). The general variation of physical and chemical parameters observed in the south-north transect in this study was due to the effect of the affluent rivers and streams.

In this study, the depth of Lake Baringo was variable spatially and temporally. The temporal variations were more pronounced with the highest depth coinciding with the rainfall season and the lowest with the dry season. Reduced depth may have been due to reduced rainfall, high evaporation rate, water abstraction from incoming rivers and the lake. On the other hand, high water levels were associated with high rainfall, increased inflows and reduced evaporation. This is attributed to flash floods, which are common in arid areas due to lack of vegetation cover. These observations have also been reported by other authors. For example, Gregory (1921) and Worthington and Riccardo (1936) reported that water level of the lake fluctuates with time and responds to alternating wet and dry periods (Kallquist, 1987; Aloo, 2002). The high water temperatures recorded in the study were mainly due to the high intensity of solar radiation in the area with air temperatures ranging between 35 °C to 39 °C (Ngaira, 2006). The high concentration of suspended solids also enhances absorption of solar energy (Wetzel, 2001). Patterson and Kiplagat (1995) attributed the high temperatures in Lake Baringo with ranges of 21.2 °C to 33.3 °C to dissolved and suspended materials. The significant variation in temperatures at different stations was due to the different times of sampling with stations sampled early in the morning recording lower temperatures than those sampled later in the day. Temporal variations of water temperatures were due to changes in seasons and water levels of the lake. Reduced depth due to decreased rainfall and increased evaporation led to high water temperatures.

Siltation from the deposition of allochthonous materials carried by River Molo and River Perkerra to the south and Mukutan stream to the west probably account for the

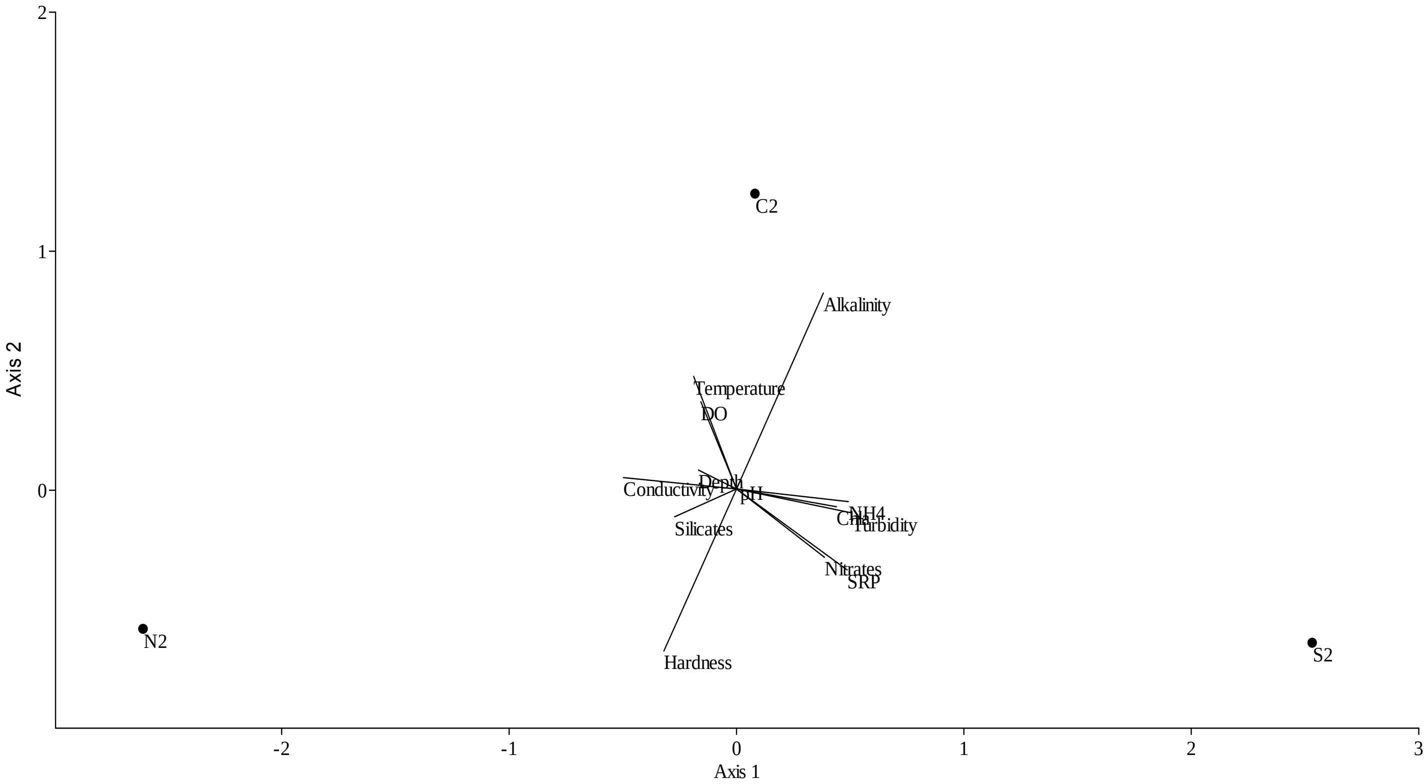

Figure 4. Principal component analyses (PCA) for sampling stations (dots) and environmental variables (arrows) in Lake Baringo between April 2008 and March 2013.

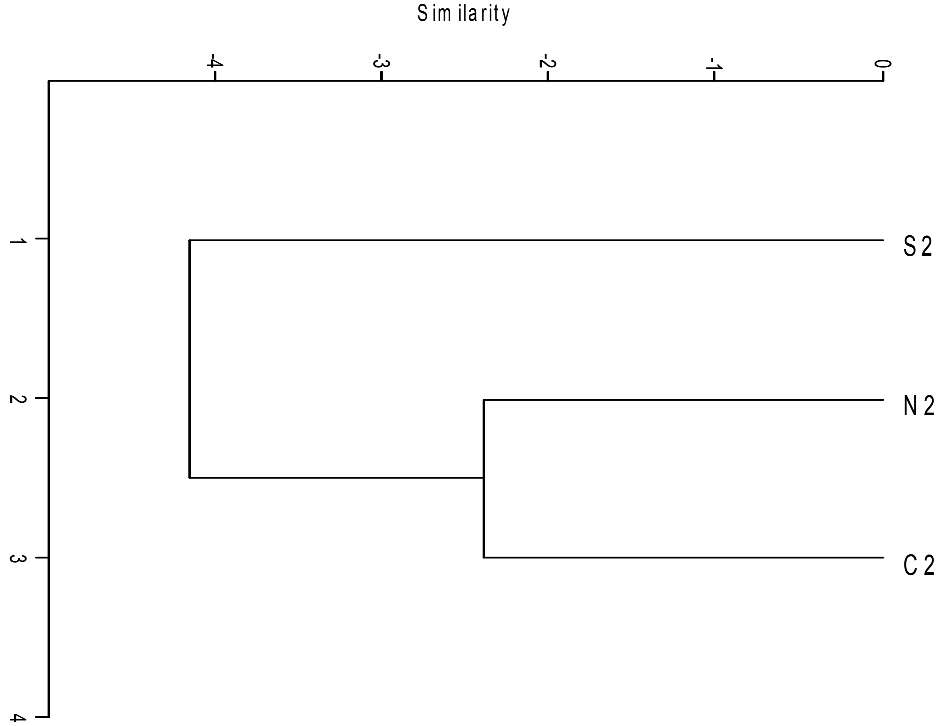

Figure 5. Dendogram clustering (Agglomerative) of sampling stations according to physico-chemical parameters in Lake Baringo between April 2008 and March 2013.

low lake depths recorded in these areas. Furthermore, established macrophytic communities in the two zones contribute to accumulation of silt by acting as traps for the incoming materials. The type of local geology, topography and meteorology (Onyando et al., 2005) coupled with anthropological activities, especially overgrazing and deforestation expose the Lake Baringo catchment to high erosion. The resulting sediments and suspended solids in turn influence the lake's depth and substratum. The muddy substratum in south of the lake is not suitable for benthopelagic pota- modromous *Labeo cylindricus* that prefers rocky habitats (Nyamweya et al., 2012). This explains the absence of the species in such areas that are dominated by *Protopterus aethiopicus* (Dipnoi) and *Clarias gariepinus* (Clariidae). The shallow soft sediments in these areas make them suitable for the spawning of *O. niloticus* while the swamps forms refuge for the larval and fingerling fishes. Sedimentation and turbidity have been found to be significant contributors to declining populations of aquatic organisms (Henley et al., 2000).

The low Secchi depths close to the mouths of rivers Molo/Perkerra and Mukutan were attributed to suspended solids brought into the lake by the rivers which reduce transparency. Turbidity results from the scattering of light in water by organic and inorganic particles. The amount of deposited suspended solids diminished with distance from the river mouths, explaining the increase in transparency from south to north. Oduor (2000) and Wahlberg et al. (2003) attributed the low transparency in the lake to resuspension of sediments by wind action. Shallowness in lakes have been reported to lead to unpredictability of seasonal events especially in windy, unstratified water bodies where resuspension of bottom sediments results in reduced water transparency (Sommer et al., 1986). The resuspension of the bottom sediments into the water column which is a common feature in such ecosystems represents a major physical factor which can impact on other abiotic and biotic variables. Low water transparency inhibits light penetration consequently reducing the euphotic zone. As a result primary production is minimal in turbid waters which has cascading effects up the food web and ultimately on fisheries production. A number of fish species have been noted to depend on sight for their feeding and reproduction. Indeed *O. niloticus* endemic to the lake feeds by sight and identifies spawning partners through secondary reproductive characteristics. This explains the reducing catches of the species with increase of turbidity of the lake over time. In contrast the catches of the introduced *P. aethiopicus*, which feeds by groping, has risen and presently dominates the lake's fishery.

The relatively high mean of dissolved oxygen concentration of 6.4 mg L^{-1} in Lake Baringo showed that the lake is well aerated. Dissolved oxygen in water is greatly influenced by the process of photosynthesis thus light intensity. This explains why dissolved oxygen values measured in the lake increased with time of sampling with areas sampled early in the morning, when there was low light intensity, having lower dissolved oxygen concentration. Turbidity also indirectly affects the level of dissolved oxygen by limiting photosynthesis through reduction of light penetration in water and this could partly explain the low concentrations of dissolved oxygen at the river mouth where turbidity were the highest. Furthermore, decomposition of allochthonous materials would also consume oxygen in such localities. The high pH in the lake can be attributed to the domination of the algal community by the *Microcystis aeruginosa* (Oduor, 2000). Blooms of this use carbon dioxide for their photyosynthetic activity and removal of the gas results in increased pH as have been reported by Purandara et al. (2003). Oxygen depletions are the most common cause of fish kills. Fish kills from oxygen depletions can range from "partial" to "total". In a partial kill the dissolved oxygen level gets low enough to suffocate sensitive species and large fish, but many small fish and hardy species survive.

In an earlier study, Kiplagat et al. (1999) attributed fluctuation in conductivity values in Lake Baringo to the nature of inflowing river waters. Therefore, high values of conductivity at the river mouths to the south and east may be attributed to high ion loads in the incoming river water. Arle (2002) reported that mineral concentrations and dilution affect the value of conductivity. The onset of rains has been observed to signal radical changes in physical and chemical variables in tropical rivers (Lowe-Connell, 1987; Chapman and Kramer, 1991). The high temperatures in Lake Baringo area accompanied by the high evaporation rates could also contribute to the fluctuations in conductivity values in the lake. During rains there is dilution of lake water resulting in decreased ion concentrations while during drought and low water levels there is an increase of these thus high conductivity levels. This was supported by the negative correlation between conductivity values and lake depth.

The frequent peaks of nutrients realized during the study were probably caused by flushing of ions into the lake after rains in the catchment. River inflow has been observed to shape chemical gradients in other lakes (Patalas, 1969) through nutrient and organic matter input. On the other hand during dry periods high concentrations of ions observed could be due to reduced water volume in the lake by evaporation. Increased concentrations of ions, due to evaporation, in shallow lakes following dry periods have been reported by Swaine et al. (2006).

Chlorophyll *a* is a measurement frequently used to estimate phytoplankton biomass and to predict eutrophication levels of freshwater aquatic ecosystems (Wetzel, 2001; Dodds, 2002). The low Chlorophyll *a* concentrations recorded in Lake Baringo can be attributed to the high turbidity resulting in low light penetration leading to low photosynthetic activity. This is shown by the increase in the Chlorophyll *a* concentration during periods of low water levels in the lake. From the results of the study, increase in depth results in the increase in light transparency which culminates in higher production, thus increasing chlorophyll *a*. However, this was not the case in this study showing that probably the water turbidity arising from the silt brought in by rivers suppressed photosynthesis.

PCA results confirmed that most nutrients enter the lake through the rivers since these were the factors that characterized station S2, a river mouth station. Characterization of station C2 by dissolved oxygen and temperature is due to the fact that this was the station which was always sampled last when temperatures and light intensity were high.

RECOMMENDATIONS

The present study provides evidence that the incoming water through rivers is the source of pollutants in form of silt, nutrients and ions. These come from the catchment and are as a result of anthropogenic activities which induce soil erosion especially farming, deforestation and keeping of large number of livestock. Increased nutrients in the lake have led to the domination of the algal community by *M. aeruginosa,* a species known to be inedible for most zooplankton and fish. Increased turbidity, worsened by frequent winds and resuspension of sediments in the lake depress photosynthesis and also reduces feeding efficiency in fish that feed by sight. Indeed the increasing turbidity in the lake water could be one of the reasons for the decreasing catches of the once dominant *O. niloticus*. Considering that the lake has no outlet, the concentration of most of these pollutants would be cumulative and remain in the lake for a long time and will worsen unless the situation is contained. There is need for restoration of the lake by addressing the problem of soil erosion and siltation in catchment so as to reduce the amount of allochthonous materials entering the lake. This can be alleviated through afforestation programmes and reduction of the number of livestock in the area. The areas around the lake should also be protected by fencing and planting suitable grasses like vetiver which can withstand water logging and drought.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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REFERENCES

Aloo PA (2002). Effects of climate and human activities on the ecosystem of Lake Baringo. P 335-347. In 'The East African Great Lakes: Limnology, Paleolimnology and Biodiversity, Odada E.O and D. O Olago (eds) Kluwer Academic, London.

Anon (2003). Lakes of the Rift Valley, Project Briefing. http://www.earthwatch. org/expeditions/harper/harper_03.pdf; accessed September 15, 2013.

APHA (2000).Standard methods for the examination of water and wastewater.20th edition.American Public Health Association Inc., New York, USA.

Arle J (2002). Physical and chemical dynamics of temporary ponds on a calcareous plateau in Thuringia Germany. Limnologia 32:83-101.

Beadle LC (1932). Scientific results of the Cambridge Expedition to the East African lakes in relation to their fauna and flora. J. the Linnean Soc. Zool. 38:157-211.

Bryan RB (1994). Land degradation and the development of land use policies in a transitional semi-arid region. In Soil Erosion, Land Degradation and Social Transition – Geoecological analysis of a semi-arid tropical area, Kenya, ed. R. B Bryan, pp. 1-30. Catena-Verlag, Cremlingen-Destedt.

Chapman LJ, Kramer DL (1991). Limnological observations of an intermittent tropical dry forest stream. Hydrobiologia 226:153-166.

Cl'ement JP, Caroff M, H'emond C, Bollinger JJC, Guillou H, Cotton J (2003). Pleistocene magmatism in a lithospheric transition area: Petrogenesis of alkalins lavas from Baringo- Bogoria basin, central Kenya Rift. Can. J. Earth Sci. 40:1239-1257.

Dodds WK (2002). Freshwater Ecology: Concepts and environmental applications. Academic Press. San Diego. 569 pp.

Dunkley PN, Smith M, Allen DJ, Darling WG (1993). The geothermal activity and geology of the northern sector of the Kenya Rift Valley. British Geological survey Research Report SC/93/1, Keyworth, Norttingham.

Gregory JM (1921). The Rift Valleys and Geology of East Africa. Seeley Service: London.

Hammer O, Harper DA T, Ryan PD (2001). PAST: Paleontological Statistics Software Package for Education and Data analysis. Palaeontologia Electronica. 4(1):1-9.

Henley WH, Patterson MA, Neves RJ, Lemly AD (2000). Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. Review Fish. Sci. 8:125-139.

Kallqvist T (1987).Primary production and phytoplankton in Lake Baringo and Naivasha, Kenya. Norwegian Institute for Water Research Report, Blinden, Oslo, 59pp.

Kiplagat WK, Njuguna SG, Francis MM, Lothar K (1999). The physico-chemical conditions of Turkwel gorge reservoir, a new man-made lake in northern Kenya. Limnologia 29:377-392.

Lowe-McConnell RH (1987). Ecological studies in fish communities. Cambridge. 33 p.

Ngaira JK (2006). Implications of climate change on the management of Rift Valley lakes in Kenya. The case of Lake Baringo.pp 133-138. In Odada EO, DO Olago, W Ochola, M Ntiba, S Wandiga, N Gichuki, H Oyieke (eds) Proceedings (Vol. 2) of 11th World Lakes Conference, 31st October to 4th November 2005, Nairobi Kenya. 623 pp.

Nyamweya CS, Mlewa CM, Ngugi CC, Kaunda-Arara B, Njiru M, Gichuki JW, Ojuok JE (2012). Aspects of the biology of *Labeo cylindricus* (Pisces: cyprinidae) in Lake Baringo, Kenya. Lakes and Reservoirs: Research and Management. 17(3):225-229. doi:10.1111/lre.12002

Odada EO, Onyando JO, Obudho PA (2006). Lake Baringo: Addressing threatened biodiversity and livelihoods. Lakes and Reservoirs: Research and Management. 11:287-299.

Oduor SO (2000). Physico-chemical Dynamics, Pelagial Primary Production and Algal Composition in Lake Baringo, Kenya. MSc. Thesis, IHE, Deft, Austria. 83 pp.

Omondi R, Yasindi AW, Magana A (2011). Spatial and temporal variations of zooplankton in relation to some environmental factors in Lake Baringo, Kenya. Eger. J. Sci. Technol. 11:29-50.

Onyando JO, Kisoyan P, Chemelil MC (2005).Estimation of potential soil erosion for River Perkerra catchment in Kenya. Water Res. Manag. 19:133-143.

Patalas K (1969). Composition and horizontal distribution of crustacean plankton in Lake Ontario. J. Fish. Res. Board Can. 26:2135-2164.

Patterson G, Kiplagat KW (1995).The influence of the diel climate cycle on the depth-time distribution of phytoplankton and photosynthesis in a shallow equatorial lake (Lake Baringo, Kenya). *Hydrobiologia* 304:1-8.

R Development Core Team (2012). R: A Language and Environment for Statistical Computing. (R. D. C. Team, Ed.). *R Foundation for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. doi:10.1007/978-3-540-74686-7.

Sarma SSS, Nandini S, Gulati RD (2005). Life history strategies of cladocerans: comparisons of tropical and temperate taxa. Hydrobiologia 542:315-333.

Sidneit MT, Fakio ALT, Maria CR, Francises AE, Adaunto F (1992). Seasonal variation of some limnological factors of Lagoa do Guarana, a varzea lake of the Rio Parana State of Mato Groso do Sul. Braz. Rev. Hydrobiol. 25:269-276.

Swaine MD, Adomako J, Ameka G, De Graft-Johnston KAA, Cheek M (2006). Forest river plants and water quality in Ghana. Aquat. Bot. 85:299-308.

Wahlberg HT, Harper D, Wahlberg NT (2003). A first limnological description of Lake Kichiritith, Kenya: a possible reference site for the freshwater lakes of the Gregory Rift Valley. South Afr. J. Sci. 99:494-496.

Wetzel RG (2001). Limnology: Lake and rivers ecosystems. Academic press. San Diego. 1006p.

Wickham H (2009). ggplot2: elegant graphics for data analysis. New York: Springer. Retrieved from http://had.co.nz/ggplot2/book

Worthington EB, Ricardo CK (1936). Scientific results of the Cambridge expedition to the East African lakes, 1930-1 No.17. The vertical distribution and movement of the plankton in Lake Rudolf, Naivasha, Edward and Bunyonyi. J. Linnean Soc. Zool. 40:33- 69.