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Dynamics of Hydrology on the Physico-Chemical Water Quality Parameters and Trophic State of Lake Baringo, Kenya

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Abstract

Lake Baringo is a freshwater lake situated in the Kenyan Great Rift Valley, characterized by a polymictic regime with southern inlets but without any visible outlet. How the inflowing rivers and the rise in lake water levels affect water quality is still unclear. In this study, samples were collected from May 2014 to June 2015 at sites S2, C1, C2, C3 and N2: S denoted southern part, C central region and N northern part; and analysed for a wide range of physical and chemical parameters and the trophic state of the lake also determined. During 2017, samples were collected from nine stations at sites designated inlet (S1, S2 and S3), Lake Centre (C1, C2 and C3) and offshore (N1, N2 and N3). Spatial differences were determined by Analysis of Variance (ANOVA). All the physicochemical parameters (i.e. for 2017) demonstrated significant ($P<0.05$) spatial variations. Equally, spatial-temporal differences were noted for one year study period of June 2014 to May 2015 ($P<0.05$). Data collected for one year indicated a somewhat different trend from what was witnessed on data of 2017. Stations that demonstrated high values of the measured parameters during the 2017 sampling (i.e. temperature for S2, 26.8^{o}C) recorded reduced levels in the one year sampling (26.0^{o}C). However, results from the 2017 study period showed variation from one station to another ($p<0.05$). The ecological status of the lake as measured by the water quality studies carried out in the present study has changed in comparison with the previous studies because the general trend is indicative of an improved system due to rise in water levels. The study recommends regular monitoring in order to discern the erratic changes witnessed with the changes in water levels leading to deviation of the physico-chemical water quality parameters from the past studies.

Key Words: Hydrology, Human Settlement, Physic-Chemical, Trophic State, Lake Baringo

INTRODUCTION

Water quality is the measure of the state or condition of water resources relative to the requirements of the biotic species and human needs. It is defined as the physical, chemical or biological characteristics of water (United Nations, 2007). Water quality in aquatic systems is important because it maintains the ecological processes that support biodiversity. However, declining water quality due to environmental perturbations threatens the stability of the biotic integrity and therefore hinders the ecosystem services and functions of aquatic ecosystems. 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). Most aquatic systems around the world, including rivers and lakes, are currently undergoing human induced changes from land-use activities centred on agriculture and industrial activities, and human settlements (Ngaira, 2006). Not unexpectedly, the character of a lake is determined by the character and magnitude of the basin draining into it, mainly because the ecosystems of lentic water bodies are closely linked to the physical, chemical and biological processes occurring within the entire watershed. The cumulative effects of the quality of the water draining from the catchments areas will ultimately influence the ecological integrity of any recipient water bodies.

In the catchments, Lake Baringo has experienced degradation of the streams, rivers and the lake itself, and consequent loss of water quality and biological diversity that threaten the well-being of the lake side dwellers by compromising their livelihoods (Odada *et al*., 2006). The rivers draining into the lake are characterized by urbanized catchments which cause a consistent suite of effects termed herein as the ‘‘urban stream syndrome’’. The riparian community earn their living through pastoralism and agro-pastoralism. As pastoralists, they keep large heads of animals which overgraze the catchment vegetation leading to enhanced soil erosion, sedimentation in streams and the lake and of course flash floods. Other pronounced anthropogenic activities in the catchments that have caused massive degradation of the lake include deforestation and conventional agricultural practices (Odada *et al*., 2006). The lake therefore, has been transformed from clear state of an ecosystem dominated by macrophytes, to turbid state dominated by algae (Omondi *et al*., 2014).

Of interest is the drastic changes in water levels of the lake that have been witnessed as from the 1960s. The lake depth has undergone several changes due to unpredictable rainfall patterns and persistent droughts in some years. Past studies have indicated that between 1969 and 1972, the average depth of the lake was 8 m. Kassilly (2002) reported a mean depth of 3 m with the deepest point being about 7 m at high water levels. These low levels persisted until early 2003 where the average depth was recorded at 1.7 m before the onset of heavy rains. It is reported that such changes resulted into reduction in size of the lake in terms of surface area from 130 $km^2$to 108 km^2 between the years 1976 and 2001 (Kassily, 2002). Odada *et al.*, (2006) reported a mean depth of 2.5 m with the deepest end of the lake being 3.5 m. With the onset of *El nino* rains that were witnessed in the country in the year 2012, the lake waters rose once again and the deepest depth of 11.27±0.12 m was documented (Omondi *et al.*, 2014). It is against the foregoing backdrop that this study explores thedynamics of hydrology on the physico-chemical water quality parameters and trophic state of L. Baringo.

MATERIALS AND METHODS

Study Area

The study was done in Lake Baringo (Figure 1), a freshwater lake in the eastern arm of the Great Rift Valley in Kenya. Lake Baringo 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 900 m to 1200 metres above sea level (Kallqvist, 1987; Owen *et al.*, 2004). The lake has a surface area of approximately 130 km^2 and a catchment of 6,820 km^2.

The area has two rainy seasons and the mean annual rainfall is 635 mm (Kassilly, 2002). 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). 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. The lake 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. The vegetation in the area is bushy and characterized by indigenous species *Acacia* spp., *Acalypha fruticosa*, *Maerua edulis* and the exotic species *Lantana camara*. The soils in the area are mainly moderately to poorly drained, very deep, strongly calcareous, saline and sodic. The texture is fine sandy loam to clay (Anonymous, 1987).

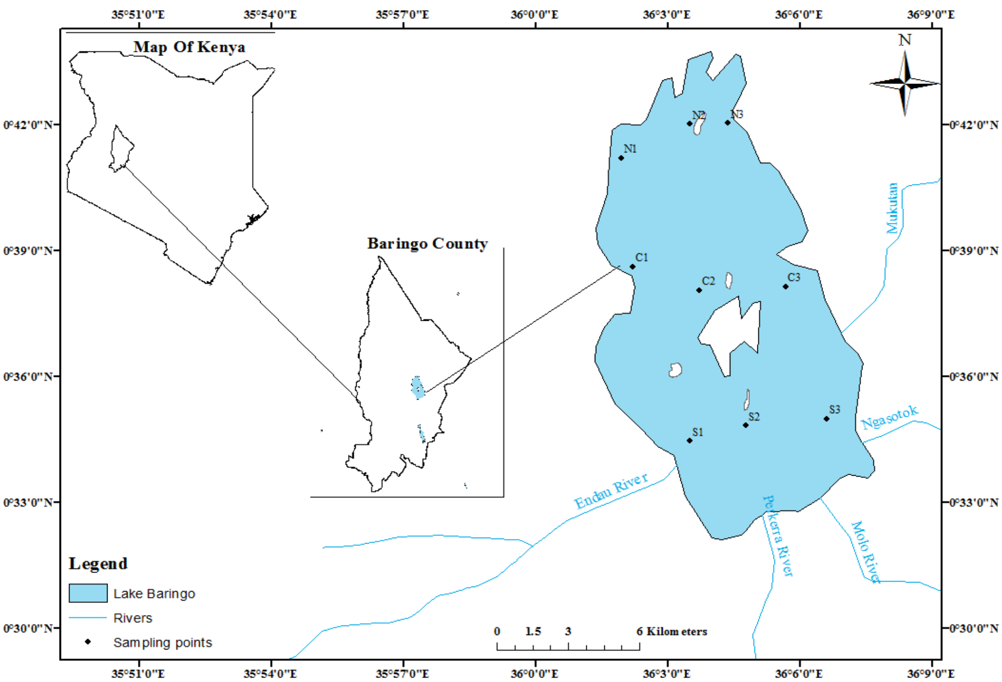


Figure 1. Map over the Study Area.

Sampling Design and Choice of Sampling Sites

Stratified random design was used for the present study. For the periodbetween June 2014 and May 2015 samples were taken at 5 geo-referenced sampling sites using Global positioning system (GPS) navigational unit (Garmin II model) (Garmin II model) based on proximity to river mouths whereas for the year 2017 sampling period all the nine stations were sampled. The geo-referencing was done at sites used during a previous expedition whereby the lake is profiled into three ecological zones. They are earmarked as southern (S1, S2 and S3), central (C1, C2 and C3) and northern (N1, N2 and N3). The stations sampled for June 2014 to May 2015 were S2 in the southern zone, three stations at the Centre of the lake (C1, C2, and C3) and N2 in the northern part.All the stations in the south and northern part of the lake were not sampled due to logistics and security reasons especially in the northern sides of the lake. All the nine stations were sampled during the 2017 study period following peace stability. Note however, that between May 2015 and the whole of 2016, no sampling was done due to insecurity in the region.

Sampling Procedure

Triplicate samples of all parameters were collected at the surface (0 m) in L. Baringo for 12 monthsfor each sampling occasion (i.e. June 2014 and May 2015; 2017). 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. Temperature, conductivity, dissolved oxygen (DO), total dissolved solids (TDS), pH, salinity and sechi depth were measured at each sampling site. The temperature, DO, conductivity and pH were measured *in situ* at each sampling sites, using a Surveyor II model hydrolab, with independent probes for each variable. Turbidity was measured *in situ* using a HACH 2100P turbidimeter.

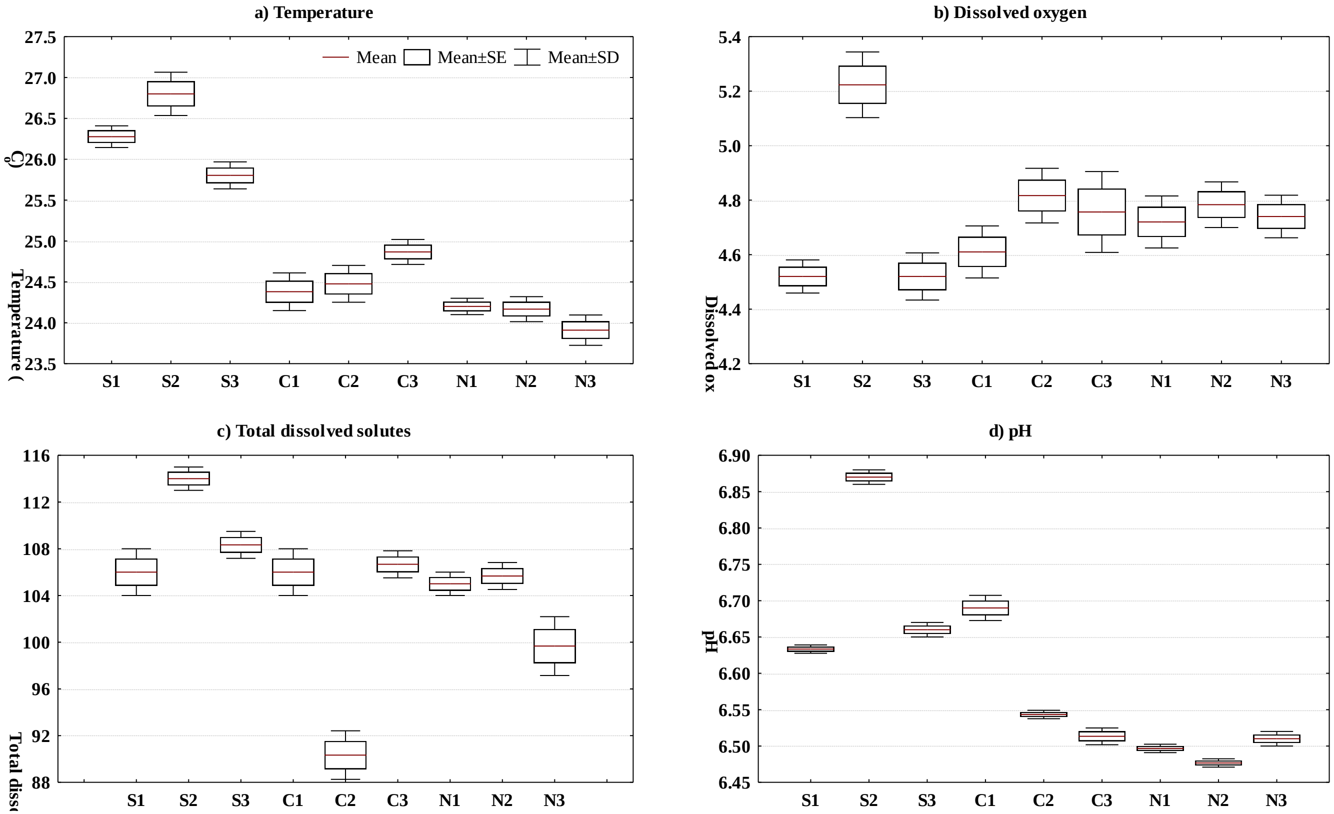
Statistical Analyses

The physico-chemical parameters were presented as means ± SD for each sampling sites. The mean differences in the physicochemical parameters (i.e. for 2017) among sites were analysed using a one-way ANOVA test whereas two-way ANOVA was used to show the spatio-temporal variations in physico-chemical parameters from June 2014 to May 2015 with time x station as the main factors. Duncan's multiples range test was used for *post-hoc* discrimination between the means that were different from each other (Michael and Douglas, 2004). Based on the measured physico-chemical parameters, the similarity of the measured parameters were compared among stations using exploratory cluster analysis. The dichotomous classification technique expressed the measured parameters in an ordered table, constructed from site–variable matrix. The outputs are viewed as dendrograms that illustrate sampling sites exhibiting similar species composition. For ease of comparison, the scale was reduced to percentage by dlink/dmax*100. All analyses were carried out using the STATISTICA for Windows software package (StatSoft 2001) and all the inferences were accepted at $\alpha = 0.05$.

RESULTS

An overview of the physical and chemical variables in L. Baringo observed at the inlet sites for the 2017 data (S1, S2, and S3), offshore site (N1, N2 and N3) and inshore sites (C1, C2, and C3) are shown in Figure 2 while the ANOVA table showing the variations of the physico-chemical parameters are shown in Table 1. All the physicochemical parameters demonstrated significant ($P < 0.05$) spatial variations. Site S2 located near inlet exhibited significantly higher temperature, DO, TDS, pH and salinity. As for temperature, sites located at the inlet recorded higher temperature than all the other sites with sites in the northern part of the lake having the lowest temperate ranges. DO in sites S1, S2 and C1 were the lowest with C1, C2,C3, N1, N2 and N3 having similar DO ranged. The pH measured at sites C2, C3, N1, N2 and N3 were less than those measured at the inshore sites C1 and inlet sites S1, S2 and S3. Salinity measured at the southern inlet sites except S2 was similar to those measured at sites C3, N1 and N2, which were generally higher than salinity at sites N3 and C2.

There were no discernable spatial variations patterns in sechi depth.


a) Temperature
Mean
Mean±SE
Mean±SD
27.5
27.0
26.5
26.0
25.5
25.0
24.5
24.0
23.5
S1 S2 S3 C1 C2 C3 N1 N2 N3
b) Dissolved oxygen
5.4
5.2
5.0
4.8
4.6
4.4
4.2
S1 S2 S3 C1 C2 C3 N1 N2 N3
c) Total dissolved solutes
116
112
108
104
100
96
92
88
S1 S2 S3 C1 C2 C3 N1 N2 N3
d) pH
pH
6.90
6.85
6.80
6.75
6.70
6.65
6.60
6.55
6.50
6.45
S1 S2 S3 C1 C2 C3 N1 N2 N3

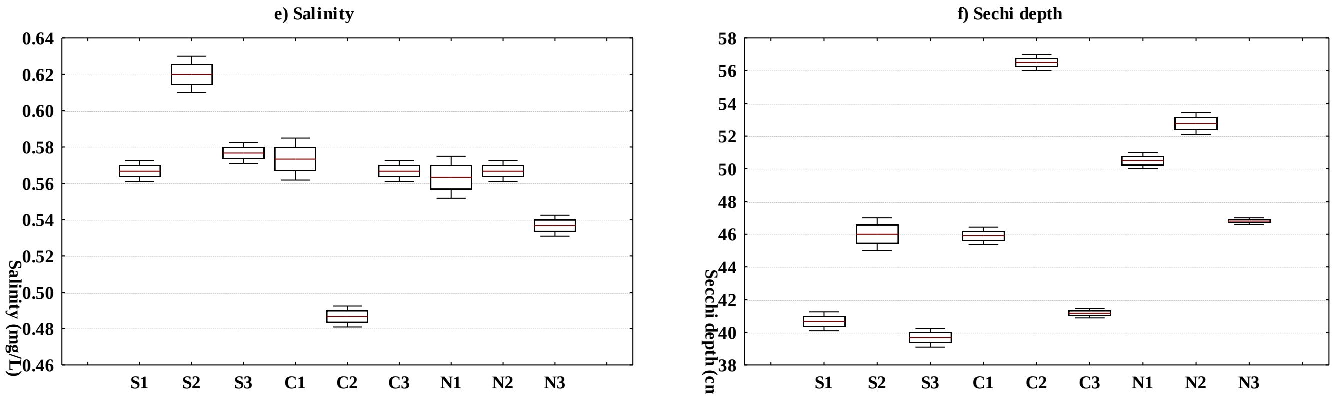


Figure 2. Summary of Physico-Chemical Parameters (n = 3 per Site) in Lake Baringo for the Year 2017.

Table 1. ANOVA Table Showing the Statistical Differences in Physico-Chemical Parameters (n = 3 per Site) in L. Baringo during the Sampling, 2017

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**P**
Secchi depth (cm)	Between Groups	674.347	8	84.293	278.912	0.00
	Within Groups	5.440	18	0.302		
	Total	679.787	26			
Temp	Between Groups	21.455	8	2.682	81.719	0.00
	Within Groups	0.591	18	0.033		
	Total	22.046	26			
DO	Between Groups	0.911	8	0.114	11.962	0.00
	Within Groups	0.171	18	0.010		
	Total	1.082	26			
TDS	Between Groups	1065.630	8	133.204	58.008	0.00
	Within Groups	41.333	18	2.296		
	Total	1106.963	26			
pH	Between Groups	0.405	8	0.051	525.875	0.00
	Within Groups	0.002	18	0.000		
	Total	0.407	26			
Salinity	Between Groups	0.031	8	0.004	66.234	0.00
	Within Groups	0.001	18	0.000		
	Total	0.032	26			

The spatio-temporal variation in the water quality parameters from June 2014 to May 2015 on the other hand is shown in Figure 3. There were significant spatio-temporal variations in all water quality parameters ($P < 0.05$) (Table 2). The water quality between June 2014 to May 2015 also showed significant differences with those sampled in 2017 ($P < 0.05$). Results for the levels of temperature showed a slight decrease in the month of July 2014 before they increased steadily until October of the same year. At this point they fluctuated again up to the month of February and March 2015 before increasing steadily in the months of April and May 2015. Of all the stations, C1 recorded the highest levels of temperature throughout the year as compared to station C3 which registered the lowest. Temperature levels did not differ so much between the sampling periods.

DO showed remarkable variations throughout the entire study period of one year (i.e. between June 2014 and May 2015) with months of July and December 2014 recording high peaks (Fig. 3). When comparing the trends exhibited in the two sampling periods (June 2014 and May 2015), there was no much difference because station S2 for example recorded 5.3 mg/l during 2017 and 5.5 mg/l in the sampling period June 2014 and May 2015.

TDS showed unpredictable trends for the sampled period of the year (Fig. 3). High peaks were noticed during the months of July, December 2014 and April 2015. C2 displayed low trends as compared to the rest of the stations whereas C1 recorded the high levels as illustrated by the trends in Figure 3.

The pH increased steadily for the months of June to August 2014 before there was a slight decline for stations C3, C1 and N2. On the other hand, stations C2 and S2 kept on increasing for the month of September before decreasing sharply until the month of December 2014. The pH then increased steadily once more for the months of January and February 2015 before another fluctuation was witnessed (Figure 3).

Similarly, hardness in all the sampled stations decreased steadily in the month of February before an upward trend was seen for the months of July to October 2014 where a remarkable decline was observed for the sampling stations S2, C1, C2 and N2 for the months of November 2014 to March 2015. Hardness shoot up again for all the sampling stations during the month of April 2015 before decreasing again sharply in May 2015.

The Secchi depth decreased continuously for all the sampling stations during the one year study period (i.e. for June 2014 to May 2015). However, it stabilized at given points such as the months of August 2014, November 2014 to February 2015 (for stations C2, C1 and N2) and then in the month of May 2015.

Euclidean clustering of the sampling stations based on the physico-chemical parameters separated the stations as shown in Figure 4.

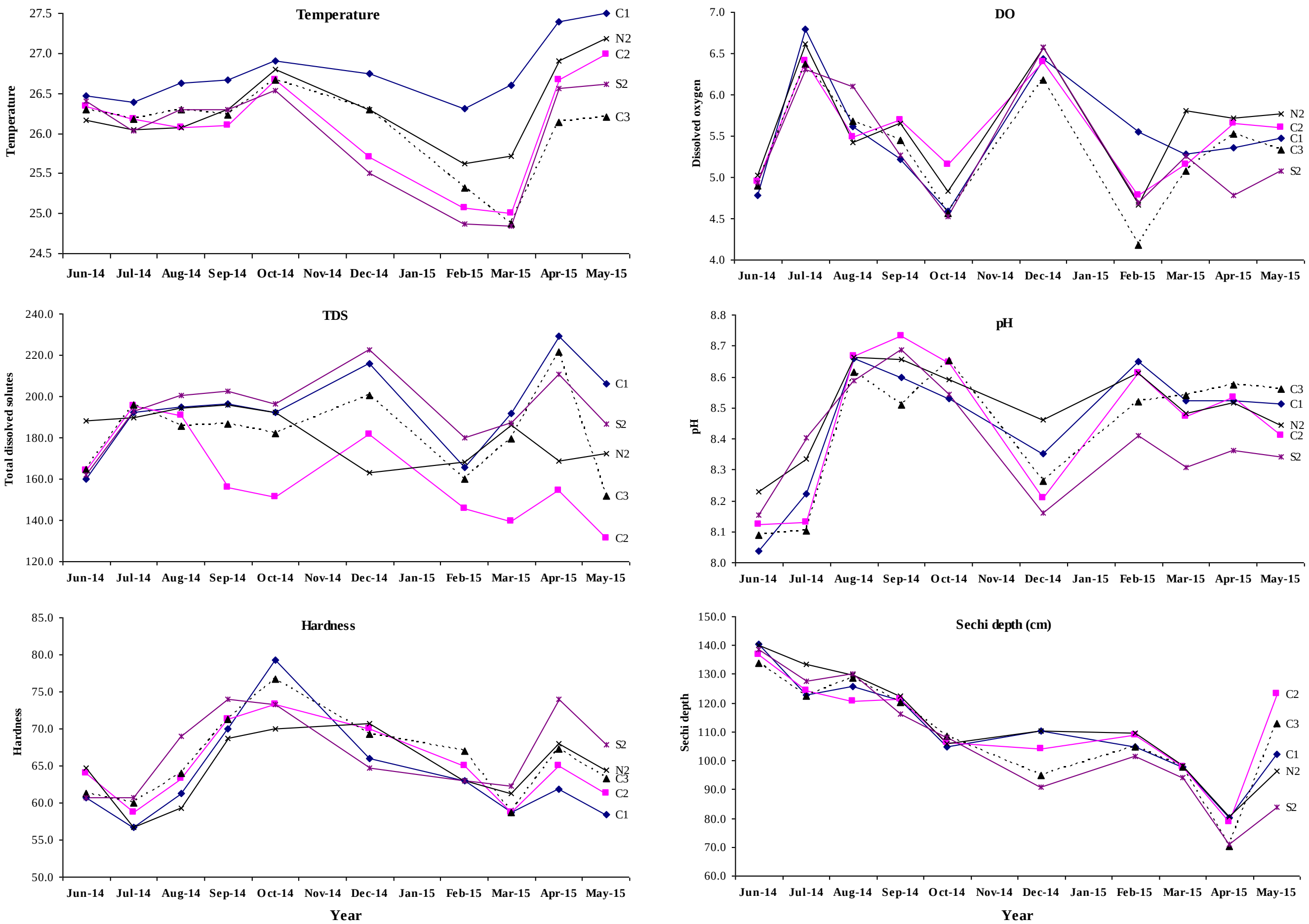


Figure 3. Spatio-Temporal Variation in the Water Quality Parameters from June 2014 to May 2015.

Table 2. Two way ANOVA Showing Spatio-Temporal (Time*Station) Variations Differences in Physico-Chemical Parameters in Lake Baringo from June 2014 to May 2015

Source of variation	Dependent variable	Sum of Squares	df	Mean Square	F	Sig.
Time*Station	Temperature	8.5063	49	0.1742	114.001	0.0000
	DO	74.3	49	1.516	53.008	0.0000
	TDS	71.733	4	1.933	5.626	0.0315
	pH	8.506	49	0.174	114.001	0.0000
	Hardness	4472	44	101.636	6.912	0.0003
	Sechi depth	45613.84	49	930.895	275.141	0.0000

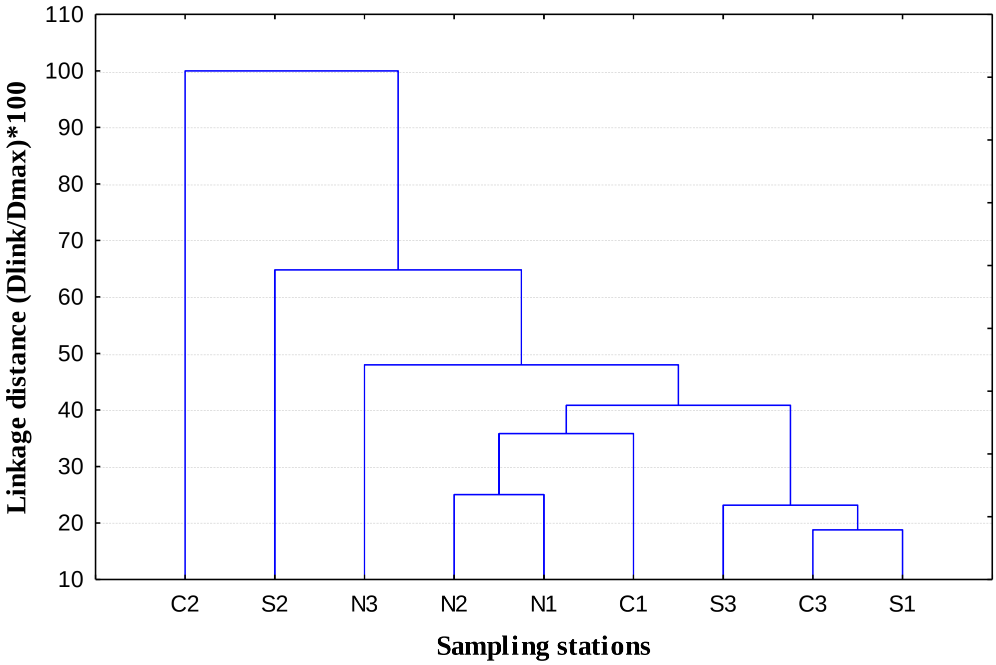


Figure 4. Dendrogram Illustrating Classifications of Stations based on Physico-Chemical Parameters (Scaling to Dlink/Dmax*100) in Lake Baringo during the Sampling Period in January 2017

DISCUSSION

The physicochemical environment of L. Baringo displayed considerable spatial and temporal variation in relation to the prevailing environmental conditions which may further be exacerbated by the driven human activities with the lake and from the catchment areas. Indeed, diverse activities have been recorded in the catchment of the lake which may drive the water quality changes in the lake (Kiplagat *et al*., 1999; Onyando *et al*., 2005; Ngaira, 2006; Odada *et al*., 2006). The physical conditions of L. Baringo were characterized by high water temperature and a low transparency throughout the years. The variation in temperature within the lake could be attributed to differences in the water depth such that the deep and shallow water in the sites translates to relatively larger water mass which takes longer to warm up and cool down. The pH is relatively high which is common for lakes of volcanic origin (Costantini *et al*., 2007).

Although past studies have reported low values for the levels of the pH in comparison to the other sites that have been attributed to the high influx of fresh water from the incoming rivers Molo, Ol Arabe, Endau, Kapthurin (Omondi *et al*., 2014), there seems to be a shift because from the present findings the northern part has witnessed low levels of pH. This may be explained by the fact that at no time does the northern part of the lake receive water from any river. Elsewhere it is argued that inlet rivers that drain into L. Baringo contribute to the increase of the pH levels (Stoof-Leichsenring *et al*., 2011). The low levels of pH that are being witnessed in the lake brings out a very interesting aspect about the fauna and flora of this ecosystem. For example, unpublished studies indicate that fish population have reduced seriously in the recent past because many fresh water fishes cannot thrive in pH levels less than 7.0. Low pH also results into low abundance of zooplankton, phytoplankton including macrophytes, and also a decline in macroinvertebrates which is characteristic of L. Baringo at the moment. According to Omondi *et al*., (2013) copepods comprises of more than 80% of the zooplankton found in L. Baringo and from research it has been established that copepods can tolerate low levels of pH (Jorgensen and Matsui, 1997) unlike Cladocerans that are scarce in this lake. Therefore, low pH may be contributing to very low numbers of the Tilapia and currently there has been a shift in the lake fishery where the *Barbus* spp. are dominating in terms of abundance as compared to the past years where *Proptopterus aethiopicus* led (Omondi *et al*., 2013). Turbidity and TDS were generally high at the mouth of incoming rivers due to the effect of surface runoff from the agriculturally rich catchment area.

The differences in environmental variables across the sampling stations in the lake can be attributed to the heterogeneity of the small sized lake characterized by inlet in the stations located in the southern stations and human settlement in the middle part of the lake which makes the lake to display heterogeneous water quality patterns. Similar results have been reported for other lakes in the region (Kitaka, 2002; Harper *et al*., 2011a,b; Ndungu *et al*., 2013). 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.

Compared to the physical factors the chemical parameters showed a higher variability. The inflow of hot springs on Kokwa Islands into L. Baringo may explain the pH~ with values around 9. The conductivity and salinity indicate the sub-salinity of the lake. Some physicochemical parameters examined in this study were considerably outside the ranges reported for other similar water bodies (Oduor, 2000; Ndungu *et al*., 2013), as well as the water quality conditions in the lake measured in earlier studies (Odour, 2000; Kitaka *et al*., 2002; Omondi *et al*., 2011; Omondi *et al*., 2014), indicating that the L. Baringo ecosystem has undergone fundamental shifts over time. These extreme variations in physicochemical parameters give this lake the distinction of displaying an extreme physical and chemical environment, which seem to interact in determining the nature and structure of the autotrophic assemblages of organisms in this aquatic system.

CONCLUSION

The present study aimed at assessing the dynamics of hydrology on the water quality attributes of L. Baringo. Concentrations of different physico-chemical parameters were determined through field measurements. The pH and turbidity were high at the southern part in comparison to other studied sites implying presence of more suspended particles around the river input region. Analysis of the variation in water quality parameters between the studied stations, provided information on the factors that influence the water quality of L. Baringo which include agricultural activities at the catchment and hydrological changes. The catchment of the lake was dominated by the agricultural activities. This information is fundamental especially in setting guidelines for effective ecosystem management of the lake.

RECOMMENDATIONS

Based on the findings of the present study, the following are the recommendations:

a. Regular monitoring is urgently required in order to discern the erratic changes that have been witnessed with the changes of water levels that has seen a major deviation of the physico-chemical water quality parameters from the past studies.
b. A holistic approach to be adopted in monitoring of the water quality of Lake Baringo, i.e. use of biological attributes such as macroinvertebrates, zooplankton, macrophytes and phytoplankton hand in hand with the physic-chemical variables.
c. There is need to sample for nutrients in the lake.
d. Lastly, in order to understand the contribution of the inlet rivers to the pollution of L. Baringo, it is important that the riverine ecosystems within the basin be monitored regularly.

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