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Research Article

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Assessment of the Spatial Variation of Water Quality Variables Along a Salinity Gradient in Lake Naivasha and Lake Oloiden

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ABSTRACT
The study was conducted monthly for one-year in Lakes Naivasha and Oloiden. It's main aim was to assess spatial variations in physico-chemical parameters along a salinity gradient in the Lakes Naivasha and Oloiden. Some water quality variables were measured insitu and water samples were collected for laboratory analysis. The depth, secchi depth, temperature, dissolved oxygen, conductivity, total dissolved solids, salinity, pH and phosphorus varied amongst the sites. Nitrates, chlorophyll-a and total suspended solids did not vary in the seven sites. There were variations in pH, dissolved oxygen and temperature with depth on contrast with salinity, conductivity and total dissolved solids. Lakes Naivasha and Lake Oloiden had a positive correlation between the dissolved oxygen with temperature: salinity with conductivity and the pH with total dissolved solids and temperature. An estuarine environment could lead to changes in some water quality variables in a non- linear form e.g., thermalcline and oxycline in Oseria. There was spatial variation in some water quality variables.

Keywords: Estuary, Non-Linear, Spatial Variation, Water Level

Introduction

A tropical lake could have extreme water level fluctuations. These changes in an aquatic environment should be considered for evaluation. The size of the littoral zone may change; during the period of low and high-water level. At instances when an aquatic environment is shallow, it acts as a sink for nutrients. Phosphorus may be attached to the substrate in the littoral zone and when the water level decreases, it releases it into the water column. Thus, water level fluctuations may have an influence on the productivity due to the interaction between the ecotones with respect to the season [1]. This influence on the first trophic level in turn affects aquatic organisms higher in the trophic level [2].

The fluctuations in the level of the lake could be seen as a disturbance to an aquatic ecosystem. Although, it maintains temporal and spatial heterogeneity for fish and other aquatic organisms [2]. Water quality is a measure of the state or the condition of a water resource in its association to biota. The ecological processes that occur in the support of biodiversity are maintained by water quality. Its changes affect the stability of an ecology and its ecosystem services [3].

The water level in Lake Naivasha increased; similar to occurrences in Lake Victoria and Lake Turkana. Lake Naivasha and Lake Oloiden are twins; since the increase in the water level led to their merging [2]. The joining of these two lakes may have an effect on the water quality and aquatic ecosystem due to their salinity differences [4]. Lake Naivasha is a fresh water while Lake Oloiden is alkaline-saline and its conductivity is higher [5].

An estuarine ecosystem may develop everywhere a salinity gradient exist. There is continuity in the flow of allochthonous organic matter which may favor a higher productivity. This transboindary between fresh water and saline (harolinium) has non-linear variations in biotic and abiotic aspects. Charges of particles change which may lead to varying modes of sedimentation on either side [6]. This Occurence changes the chemical equillibrium which may impact pH due to ions and dissolved substances concentration [7].

Merging of Lake Oloiden with Lake Naivasha may lead to the later's salinization. This may lead to changes in the mixing

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properties. Salinity may induce suspended matter to aggregate and flocculate increasing penetration of light which impacts photosynthesis. At the establishment of a salinity gradient there is reduced mixing and solute transport. It may hinder interaction between the surface and the bottom e.g., oxygen and nutrients [7].

There have been changes that may have taken place over a period of time due to the increase in the water level and the merging of the Lake Oloiden with Lake Naivasha [4]. The mixing of fresh and saline water may lead to physical and chemical changes in the properties of water [8]. Thus, the aim of the study was to assess spatial variations in physico-chemical parameters along a salinity gradient in the Lakes Naivasha and Oloiden.

Materials and Methods

The study was carried out monthly for one year (2020-2021) in the Lakes Oloiden and Naivasha (Figure 1). The Lake Naivasha is 100km Northwest of Nairobi and it's located at: 00046'S,36022'E, an altitude of 1890m. The Lake Oloiden is located at: 00050'S,36017'E, an altitude of 1900m and its 20km from Naivasha town. Lake Oloiden was separated from Lake Naivasha by a papyrus reef and they connect in high-water level seasons [4,5,9,10]. The two lakes merged due to the increase in the water level in the Rift valley lakes. The study sampling sites were: Oloiden station 1 (ST1), Oloiden station 2 (ST2), Oseria, Korongo, Crescent, Midlake and Malewa. A transect was drawn along the salinity gradient from Lake Oloiden (Oloiden ST1) to Lake Naivasha (Malewa). Additionally, two sampling sites were added in Lake Naivasha.

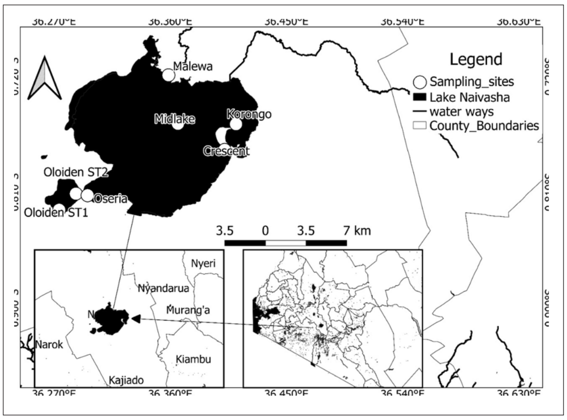

Figure 1: Map showing the Lake Oloiden and Lake Naivasha.

Physical Parameters

The depth and secchi depth (using a 23cm secchi disk) were measured in the respective study sites.

Water Quality

physical-chemical parameters were measured insitu using a YSI multiparameter meter. Variables that were measure insitu include; temperature, dissolved oxygen (DO), pH, total dissolved solids (TDS), salinity. The measurements were done at the surface and to the respective depths of the sites at an interval of 1m. Water was collected below the surface in polyethene containers that were rinsed in acid water and stored in a cooler box for laboratory analysis. These samples were used in analysis of nutrients (nitrates and orthophosphates), chlorophyll-a and total suspended solids. The water sample obtained were be filtered (in duplicates, using a vacuum pump) onto 47 µm (diameter) filter paper in Whatman's GF/C glass fiber placed onto filtering funnel. The laboratory analysis was done using the standard methods [11,12].

Statistical Analysis

One-way analysis of variance was done in Statistical Package for Social Scientists (SPSS) and Tukey multiple comparison was the post hoc ($\alpha=0.05$). The relationship between the various water quality variables was investigated using Pearson's correlation in SPSS.

Results

Physical Parameters

The depth and secchi depth were significantly different with the study sites ($P<0.05$). The Crescent had the highest depth and secchi depth while Malewa was the shallowest and Oloiden ST1 had the lowest secchi depth (Figure 2a and b)

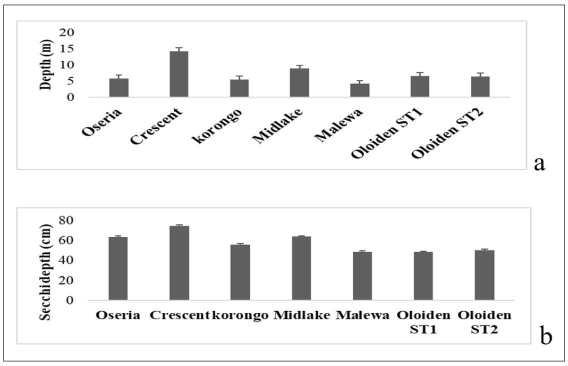

Figure 2: The lake depth (a) and secchi depth (b) in various study sites

Physico-Chemical Parameters

The temperature and dissolved oxygen were significantly different in the respective study sites. Midlake's temperature was distinct and it had the highest DO while Korongo's was the lowest (Figure 3a and b).

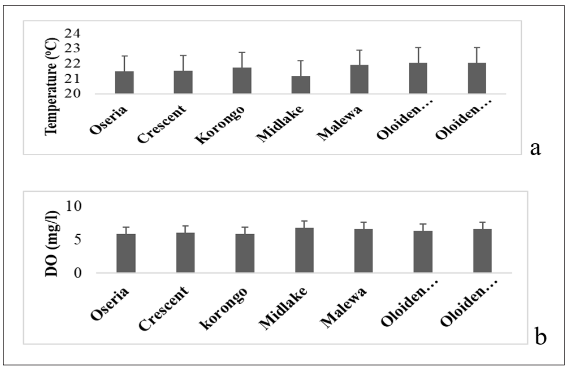

Figure 3: Temperature (a) and dissolved oxygen (b) in the various study stations in the Lakes Naivasha and Oloiden.

Conductivity and total dissolved solids were significantly different with respect to study sites and Oloiden ST2 had the highest: 0.59 ± 011µS/m and 0.42 ± 0.077mg/l respectively (Figure 4a and b).

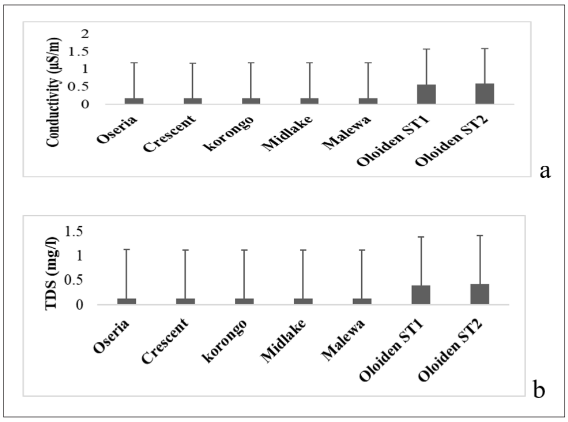

Figure 4: The water conductivity (a) and total dissolved solids (b) in the respective study sites of Lake Naivasha and Lake Oloiden.

The salinity and pH were significantly different with respect to the stations and Oloiden ST2 and Oloiden ST1 were the highest respectively (Figure 5a and b).

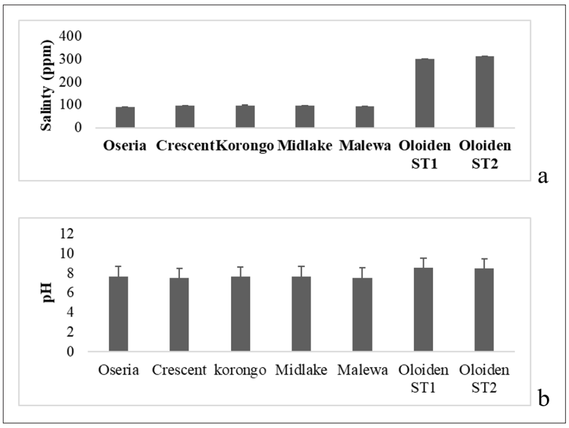

Figure 5: Salinity (a) and pH (b) of Lake Naivasha and Lake Oloiden study sites.

Nitrates were not significantly different in the study sites while the phosphates were significantly different (Figure 6a and b). Oloiden ST2's (0.41 ± 0.23mg/l) phosphates were the highest while Midlake's (0.16 ± 0.13mg/l) were the lowest.

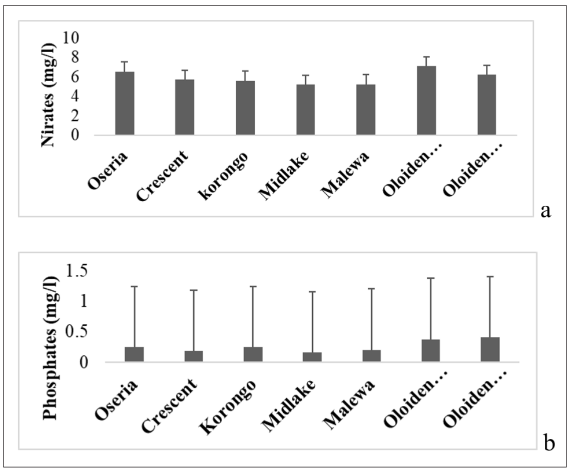

Figure 6: The nitrates (a) and phosphates (b) in the Lakes Naivasha and Oloiden.

The chlorophyll-a and total suspended solids were not significantly different with respect to study sites (Figure 7a and b).

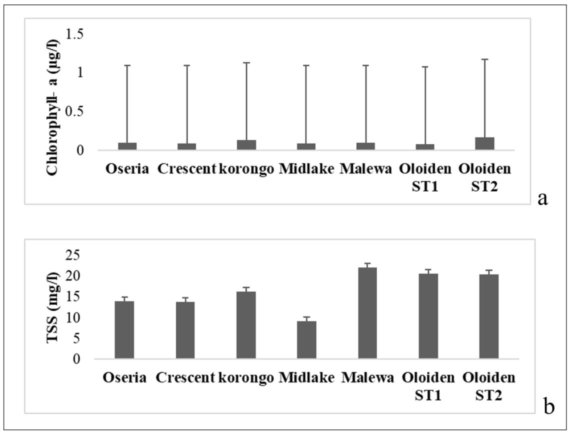

Figure 7: The chlorophyll-a (a) and total suspended solids (b) in the respective study sites.

Variation of Select Physico-Chemical Parameters with Depth

Temperature

A slight thermocline was noted in Oseria (Figure 8). The temperature at the Crescent did vary with the depth and it was distinct at 0m (22.3 ± 0.87 °C) and 11m (20.65 ± 0.07 °C). The temperature declined with respect to the depth at Korongo and the surface (highest, 22.48 ± 1.28 °C) and 6m (lowest, 21.02 ± 0.85 °C) were distinct. The temperature varied with the lake depth in the Midlake with the surface (22.33 ± 1.31 °C) and the 9m (20.17 ± 1.25 °C) being distinct. The variation of the temperature with the depth (Malewa) was significant and there was a slight increase at the 9m depth. The temperature decreased with the increase in depth in Oloiden ST1 and Oloiden ST2 and the highest was 0m (23.12 ± 1.41 °C) and lowest at 7m (20.53 ± 0.55 °C).

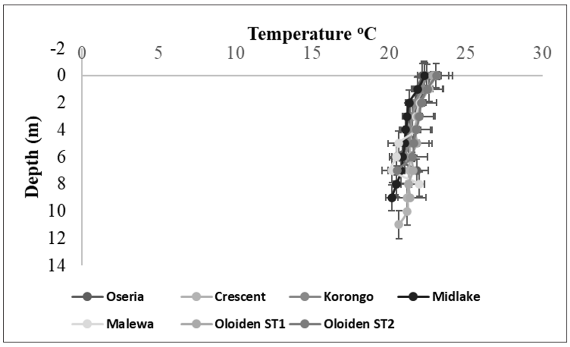

Figure 8: The variation of the temperature with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

Dissolved Oxygen

The variation of DO with the depth was significant in Oseria (declined with increasing depth) (Figure 9). There was a constant decline from the surface in the Crescent and the lowest was at 10m (3.60 ± 1.7mg/l) while the highest was at 0m (8.13 ± 0.58mg/l). In Korongo the DO varied with the respective depths and was highest at the surface and lowest at 6m. The DO was significantly different with respect to the depth at the Midlake and the highest was at the surface while its lowest was at 9m. The dissolved oxygen varied with respect to the lake depth in

Malewa and it increased at 5m. The DO varied with the depth in Oloiden ST1 and 0 m (8.65 ± 1.86mg/l) and the 8 m (2.92 ± 4.64mg/l) were distinct. Oloiden ST2 had variation of the DO and 7m (1.91 ± 1.49mg/l), 6m, 4m and 1m (8.95 ± 2.06mg/l, highest) were distinct.

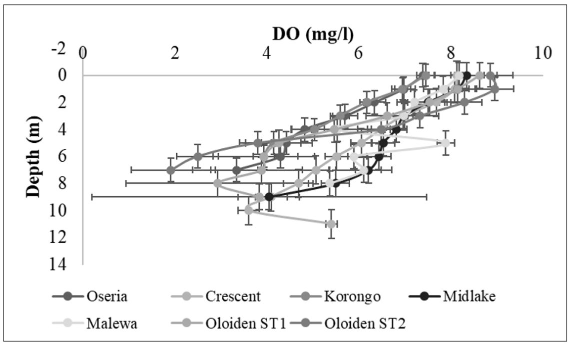

Figure 9: The variation of the dissolved oxygen with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

Conductivity

The variation of conductivity (all sites) with the depth was not significant (Figure 10).

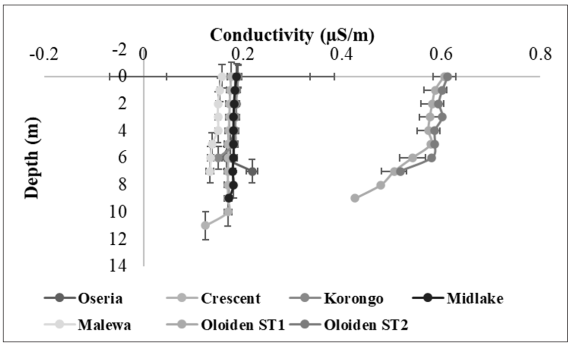

Figure 10: The variation of the conductivity with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

Total dissolved solids

The variation of total dissolved solids with the depth was not significant in all the sites (Figure 11).

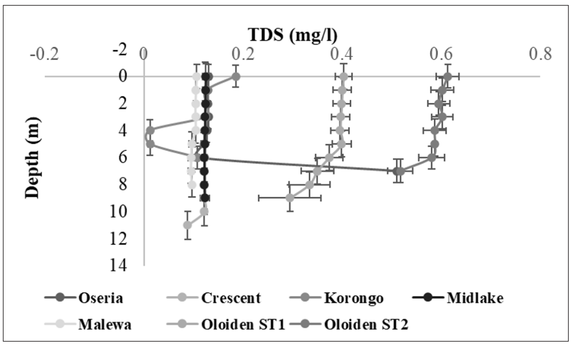

Figure 11: The variation of the total dissolved solids with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

Salinity

The variation of salinity with the depth was not significant in all the respective study sites (Figure 12).

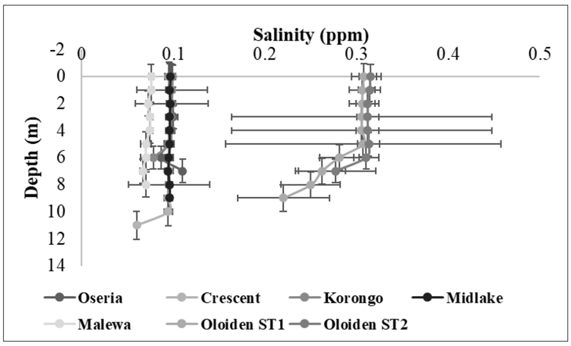

Figure 12: The variation of the salinity with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

pH

The variation of the pH with the depth was significant in Oseria and an increase at the 7th meter depth was noted (Figure 13). Crescent's pH varied with the depth and it increased at 4m and 11m. The pH was significantly different with respect to the depth in Korongo while 5m (lowest) and 0m (highest) were outstanding. Oloiden ST1's pH varied with the lake depth; it declined with the increase in the depth while Oloiden ST2's was not significant. Although, the pH was distinct at the following depth; 9m, 8m, 1m and 0m (8.75 ± 0.192, highest).

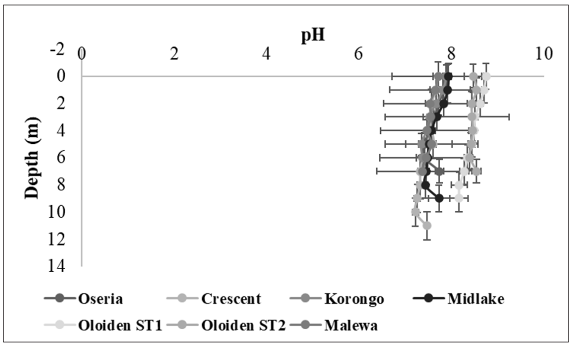

Figure 13: The variation of the salinity with depth in the respective study sites of the Lakes Naivasha and Oloiden (Error bars=SE).

Correlation Among Water Quality Variables in Lake Naivasha

The dissolved oxygen, total dissolved solids and pH were positively correlated with the temperature (Table 1). On the other hand, salinity was negatively correlated with the temperature. The salinity and pH were positively correlated with the dissolved oxygen (DO). Conductivity associated positively with salinity and pH. The variables that were negatively correlated with the DO were conductivity and total dissolved solids. Salinity had a negative association with the depth and secchi depth. The TDS associated positively with the pH and negatively with depth.

Table 1: Multiple Correlation Matrix (pearson's r value) of Physical-Chemical Parameters in the Lake Naivasha (=p<0.01, *=p<0.05, do=dissolved oxygen, tds=total dissolved solids, tss=total suspended solids and chl-a=chlorophyll-a).**

Variable	Temperature	DO	Conductivity	TDS	Salinity	pH	TSS	Depth (d)	Secchi d
Temperature	1								
DO	0.21**	1							
Conductivity	0.35	-0.329**	1						
TDS	0.08*	-0.359**	0.3455	1					
Salinity	-0.139**	0.301**	0.828**	0.750	1				
pH	0.198**	0.300**	0.085*	0.132**	-0.19	1			
TSS	0.048	0.114	-0.083	0.005	-0.021	-0.031	1		
Depth	0.065	0.001	-0.181*	-0.211*	-0.386**	-0.011	0.008	1	
Secchi depth	-0.012	0.058	-0.248**	-0.167	-0.452**	0.095	0.016	0.149	1
Chl-a	0.138	0.072	0.00	-0.049	-0.24	-0.113	0.130	0.06	-0.123

Correlation Among Water Quality Variables in Lake Oloiden

The dissolved oxygen, conductivity and pH were positively correlated with the temperature (Table 2). The depth and pH were positively correlated with the dissolved oxygen while salinity and total dissolved solids were negatively correlated. Salinity, pH and total dissolved solids had a positive association with the conductivity. Total dissolved solids had a positive association with the salinity and pH while the pH was positively correlated with the salinity.

Table 2: Multiple Correlation Matrix (Pearson's R Value) of Physical-Chemical Parameters in the Lake Oloiden

Variable	Temperature	DO	Conductivity	TDS	Salinity	pH	TSS	Depth (d)	Secchi d	Chl-a
Temperature	1									
DO	0.257**	1								
Conductivity	0.142**	-0.329	1							
TDS	0.098	-0.35**	0.934**	1						
Salinity	0.031	-0.379**	0.949**	0.931**	1					
pH	0.288**	0.154**	0.166**	0.135*	0.152**	1				
TSS	0.162	-0.040	0.148	0.124	0.013	-	1			
Depth	0.169	0.452**	-0.18	-0.265	-0.264	-0.345	-0.362	1		
Secchi d	0.019	-0.053	0.043	0.065	0.068	0.061	-0.13	0.121	1	
Chl-a	0.047	-0.161	0.191	0.205	0.24	0.16	-0.57	-0.245	-0.030	1

Discussion

Physical-chemical variables e.g., salinity, total dissolved solids, nitrates, dissolved oxygen, depth, temperature are important in determining the distribution and diversity of aquatic biota [13].

The water level has risen n the Lake Naivasha and Lake Oloiden whose depth used to be: 4-6m and 3-5m respectively [3,14,15]. Crescent was the deepest while Malewa was the shallowest and it could be attributed to siltation as River Malewa discharges at this site [15]. The lake level is important since it affects dynamics of turbidity, its decline leads to increased turbidity [3]. The overall secchi depth was >60cm and in comparison, to previous findings there has been an increase [1,2,4].

All the study sites had a temperature that was greater than 20 °C which was concurrent with the previous findings in Lake Naivasha [16]. Oloiden ST1 and ST2 had a higher temperature as compared to the rest of the study sites. This finding is associated with Lake Oloiden's higher temperature [4,16]. All the sites' temperature declined from the surface. The Lake Naivasha had a slight increase at the bottom: Oseria 's temperature increased slightly at 4m and at 7m; Malewa's increased at the bottom and thus showing a slight thermocline. This could be attributed to limited mixing due to water level rise [17]. Oseria was estuarine; thus, salinization in a fresh water body may cause changes in the mixing properties [7]. A salinity gradient may cause thermal gradients, i.e., Oseria [7,18].

The dissolved oxygen varied with respect to the study sites; although, it was lower than the previous research findings [4]. All study sites' dissolved oxygen declined from the surface; although, a slight increase was noted at the bottom in Oseria and at 4m in Malewa (oxycline). The rise in the Malewa site could be attributed to discharge from the Malewa River which may have had a higher dissolved oxygen [16]. The slight oxycline in Oseria could be due to low mixing and salinity's spatial variability [18].

The conductivity varied in each of the study sites. Oloiden ST1 and ST2's conductivities were higher as compared to the rest. However, the conductivity of Lake Naivasha and Lake Oloiden were much lower than before which could be associated with the increase in water level causing a dilution. The conductivity did not vary with respect to the depth in the study sites [4,16]. Total dissolved solids were higher in Oloiden ST1 an ST2. The TDS varied in each study site and Oloiden ST1 and ST2 were higher as compared to Lake Naivasha study sites. It may be associated salinity which may influence ionic composition [7]. There was no variation with depth.

Salinity is an environmental factor with a decisive role that is definitive of functional characteristics and the structure of an aquatic environment [6]. Oloiden ST1 and Oloiden ST2 has a higher salinity as compared with the Lake Naivasha study sites [4]. The pH varied with sites and Lake Oloiden's were higher; although lower than the previous findings which could be due to dilution [1,4]. It declined with depth in all the sites with the exception of Malewa and Oloiden ST2. A pH rise at the bottom was noted: Oseria's and Midlakes's rose at the bottom while Crescent's rose at 4m and 10m. This could be attributed to low mixing due to increased water level [17]. The pH declined with depth in Oloiden ST1 on contrary to Oloiden ST2's. This could be associated with non-linearlity of processes along a salinity gradient [6,7].

Nutrient distribution is a determinant on the fertility of a water body [19]. Nitrates were similar in all the study sites despite the salinity differences. Previous studies showed no association of denitrification with salinity [20]. The nitrates range was 4.56-5.54mg/l which was higher as compared to the previous findings in the Lake Naivasha of 0.167-0.0247mg/l. It may be attributed to agricultural runoff from the catchment [16]. There was variation in the phosphates with respect to study sites; although its range was similar to previous findings in Lake Naivasha. Lake Oloiden's phosphates were higher as compared to Lake Naivasha's study sites. These findings were contrary to previous findings; where phosphates decreased with the increase in salinity [7].

Most phytoplankton contain photosynthetic active pigments e.g., chlorophyll-a that enables them to convert carbon dioxide into complex organic molecules by utilization of energy (sunlight). Chlorophyll-a was similar in all the study sites. Its range was 0.076-0.17µg/l which was lower than the previous findings in Lake Naivasha (0.32-0.42mgl-1) [1]. Previous studies have shown an inverse relationship between the chlorophyll-a and the water level rise in the Lake Naivasha [17]. The total suspended solids were not varied between the sites and they were similar to previous findings in Lake Naivasha [16].

In the Lake Naivasha: as the temperature increased, the pH and dissolved oxygen increased. This couod be due to photosynthesis; thus, leading to the production of oxygen and hydroxide ions [18]. The increase in the conductivity and total dissolved ions may lead to a decrease in dissolved oxygen and an increase in the salinity and pH. The conductivity reduced with increase in depth and secchi depth. An increase in total dissolved solids led to an increase in the pH due to ions; a finding similar to previous [2,16]. The TDS and salinity decreased with an increase in the depth. A high conductivity and salinity led to the reduction in the secchi depth. The association of depth and secchi depth with TDS and salinity was contrary to previous research findings and it may be due to salinity gradient [7].

As the temperature increased the conductivity, DO and pH increased in the Lake Oloiden. pH change occurs when carbon dioxide is utilized. The pH rises could be due to increase in hydroxide levels during photosynthesis. Sunlight may lead to increase in temperature which may result to production of DO as a by-product. The increasing in carbon dioxide during respiration may lead to decrease in pH [21,22]. Dissolved oxygen increased with an increase in the pH and salinity. Total dissolved solids and conductivity increase led to a decrease in the dissolved oxygen. Two results that were associated with the sissolved oxygen shows non-linear variation which may be associated with a salinity gradient [7]. The increase in the total dissolved solids led to an increase in the pH [4]. The salinity correlated negatively with the depth and secchi depth contrary to the previous findings [7].

Conclusion

There was spatial variation in some water quality variable. More research is recommended along the salinity gradient due to changes in the abiotic factors in a non-linear form.

Acknowledgement

This study was undertaken in Lake Naivasha through the Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha station. Our gratitude is extended to all the staff for aiding in acquirement of samples space for laboratory analysis.

Conflict of Interest

There is no conflict of interest from all authors and there are no financial implications attached in the research.

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