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Spatial and temporal variation in water quality between the Lakes Naivasha and Oloiden in the Kenyan Rift Valley

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Abstract

Lakes Naivasha and Oloiden merged due to the rise in the water level in the former. A study was conducted for one year in an endeavor to investigate spatial temporal variation of select physical and chemical parameters between the Lakes Naivasha and Oloiden. The water quality was sampled monthly in each site in Lake Oloiden and Lake Naivasha by measuring some water quality variables insitu and collection of water samples for laboratory analysis. The water depth and the secchi depth were measured in each site while some physical-chemical parameters were measured insitu using a YSI Multiparameter probe. Nutrients (phosphates and nitrates), total suspended solids, chlorophyll-a analysis was done in the laboratory using the standard methods. The lakes depth and the secchi depth have increased in both lakes. The phosphates varied site-wise and chlorophyll-a concentration has decreased post water level rise. Lake Oloiden's temperature, pH, conductivity and salinity were higher as compared to the Lake Naivasha's. The principal component analysis showed 4 principal components (PCA-1 to PCA-4) which accounted for 94.7% of the variation. PCA-1 and PCA-2 biplots suggested: a link between chlorophyll-a to orthophosphates, nitrates, phosphates (Oloiden ST1 and ST2). Oseria and Korongo sites were closely associated with the secchi depth, lake depth, pH and salinity. 4 distinct clusters were noted: Crescent, Malewa, midsection (Midlake, Korongo, Oseria) and Lake Oloiden (Oloiden ST1 and ST2). The increase in the water level and the merging of saline and fresh water ecosystem led to the creation of a salinity gradient; an area where abiotic and biotic processes are non-linear. There was spatial temporal variation in water quality among the sites. Analysis of variance in water quality in the Lake Naivasha and Lake Oloiden provided an insight about water quality status: associations between water quality variables and sites may aid in effective management decisions.

Key words: Physico-chemical parameters, Principal component analysis, Spatial temporal variation

1.0 INTRODUCTION

Lake Naivasha is a Ramsar site due to its diversity; fauna and flora (Ndungu *et al*., 2014). It is a tropical fresh water ecosystem and besides it is Lake Oloiden; changes from fresh to saline depending on the water levels (Ballot *et al*.,2009; Obegi *et al*., 2021). Lake Oloiden was separated from Lake Naivasha by a papyrus reef and they connect at high-water level seasons (Aloo *et al*., 2013; Ballot *et al*., 2009; Clark *et al*., 1989; Lyngs, 1989). The two lakes have merged due to the increase in the water level in the Rift valley lakes. The Lake Naivasha changes seasonally and has long term fluctuations in water levels. The hydrological changes that have been taking place may be associated with water abstraction for horticulture, domestic use and industrial use (cooling of turbines in geothermal power generating plants). The increase in the water level in the Lake Naivasha may be attributed to climate change; rainfall patterns. The current water level rise is associated with an increase in the rainfall and increased river discharge into the Lake Naivasha (Hubble and Harper, 2002; Ndungu *et al*., 2013; Obegi *et al*., 2021).

The ecological processes that occur in the support of biodiversity are maintained by water quality. This has an effect since it risks stability of biotic integrity that may be a hindrance to ecosystem services and the functioning of an aquatic ecology. Water quality is a measure of the state or the condition of the water resource in association to the human, biotic species, physical, chemical and biological characteristics of water. The change in the water quality may be attributed to perturbations in the environment: risking the stability of the biotic integrity (hindering ecosystem services and functioning of the aquatic ecology) (Ndungu, 2014). water quality variation affects the adaptability of aquatic fauna and Flora. Variation in water quality may have an effect on aquatic integrity, functioning and structure of aquatic organisms (Omondi *et al*., 2019).

Fluctuations in the lake water level may have an influence on productivity; since physico-chemical parameters are interlinked with biological composition i.e., plankton (Hubble and Harper, 2002; Ballot *et al*., 2009). Variations in water quality can only be noted by a monitoring program which in the long run results in huge matrices; that call for a multivariate approach in analysis and interpretation (Ndungu *et al*., 2014). The main aim is to (i) to investigate spatial and temporal variation of select physical and chemical parameters between the Lakes Naivasha and Oloiden; (ii) assess a correlation between water quality using multivariate analysis and (iii) evaluate similarities and dissimilarities between the different sites in the Lakes Oloiden and Naivasha.

2.0 MATERIALS AND METHODS

2.1 Description of the study area

The study was done in Lake Oloiden (00^{o}50'S, 36^{o}17'E) and Lake Naivasha (00^{o}46'S, 36^{o}22'E). The study sites were: Oloiden ST1, Oloiden ST2, Oseria, Midlake, Malewa, Crescent and Korongo (**Figure 1**).

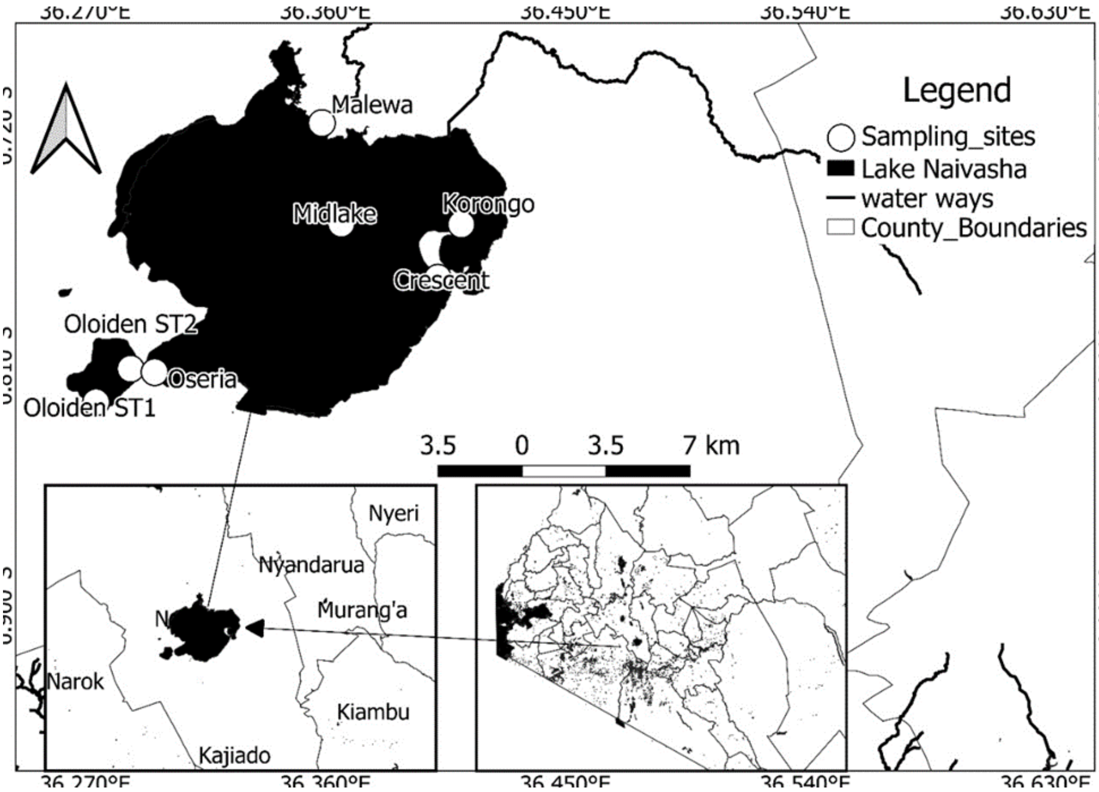

Figure 1. A map of the study sites in the Lakes Naivasha and Oloiden (Openstreetmap.org, 2021).

2.2 Sampling and analysis

The Sampling was done in all sites once per month, consistently for one year (August, 2020 to July, 2021). Some water quality variables were measure insitu, during sampling water was collected (in duplicate) below the surface in each site sampled; using 1L high density propylene plastic sampling bottles (rinsed in acid water). They were transported in a cool box with ice to the laboratory for analysis.

2.2.1. Physical parameters

The physical parameters that were measured on site are: secchi depth (cm) and depth (m). The water transparency was measured using a 23cm secchi disk (Nyangau, 2021).

2.2.2 Physico-chemical parameters

Some water quality variables were measured insitu using a YSI multiparameter meter below the lake surface: temperature, conductivity, total dissolved solids (TDS), pH, salinity, dissolved oxygen (DO) (Ndungu *et al*., 2014).

2.2.3 Laboratory analyzed variables

The following variables were analyzed in the laboratory: total suspended solids, chlorophyll-a and nutrients.

2.2.3.1 Total suspended solids and nutrients

Total suspended solids (TSS) were analyzed: by weighing a 0.45μm filter paper, before filtering (200 ml) through a prewashed GF/C glass fibered filtration unit and drying (filter paper) at 105 ^{o}C in an oven. Determination of orthophosphates (PO_3^{-4}-P) was done with molybdenum blue ascorbic method while nitrates (NO_3^{-}-N) were determined by colorimetric methods after water filtration (APHA, 2005a).

2.2.3.2 Chlorophyll-a

Chlorophyll-a was analyzed using Photometric absorbance method: obtained from chlorophyll-a extracts at 630nm, 647nm, 664nm and 750nm (wavelengths). Obtained after filtration, extraction in 90% acetone (10ml) and centrifuging for 20 minutes (APHA, 2005b). Chlorophyll-a in the water samples was calculated using the formular below.

$$Chl - \bar{a} = \frac{11.85(D664 - D750) - 1.54(D647 - D750) - 0.08(D630 - D750) * VE}{VS * \delta}$$

Where, D630, D647, D664, D750 are wavelengths 630, 647, 664 and 750nm, VE is the volume of extract (ml), VS is volume of water sample filtered and δ is the optical path length (cm) (Huang and Cong, 2007).

2.2.4 Statistical analysis

One-way Analysis of the Variance was used in analysis respective parameters (carried out in the Statistical Package for Social Scientist (SPSS)) and a post hoc analysis was done using Tukey pairwise comparison. Principal component analysis (PCA) (correlation), cluster analysis (CA) and discriminant analysis (DA) were utilized in data analysis at α= 0.05.

Kaiser-Meyer-Olkin (KMO) and Bartlett's test were done. The PCA and CA was done by Statgraphics 19.1.1.

3.0 RESULTS

3.1 Physico-chemical parameters

The lake depth was significantly different with the respective study sites ($P<0.05$) with Malewa and Crescent being distinct. The secchi depth was significantly different with respect to the sites ($P<0.05$) and distinct were: Crescent and Oloiden ST1. The temperature was significantly different between the sites ($P<0.05$) and the Midlake was distinctly high. The dissolved oxygen was significantly different between the study sites ($P<0.05$) with Korongo and Midlake being outstanding. The phosphates, total dissolved solids (TDS), conductivity, pH and salinity were significantly different ($P<0.05$) and Oloiden ST1 and ST2 were higher than the rest of the sites. The total suspended solid (TSS), nitrates and chlorophyll-a were not significantly different with the respective study sites and the lakes ($P>0.05$) (**Table 1**).

Table 1. Water quality in the various sites in Lakes Oloiden and Naivasha (DO: dissolved oxygen, TDS: total dissolved solids, TSS: total suspended solids and Chl-a is chlorophyll-a).

	Oloiden ST1	Oloiden ST2	Oseria	Midlake	Malewa	Crescent	Korongo
Depth (m)	6.39±1.6	6.46±0.5	5.84±1	8.9±0.3	4.16±1.3	14.25±1.9	5.49±0.6
Secchi depth (m)	0.48±11.7	0.51±9.03	0.64±10.8	0.64±8.88	0.49±7.47	0.74±14.9	0.56±8.15
Temperature (^{o} C)	21.96±1.12	21.12±3.25	20.8±2.8	20.08±3.84	21.97±1.23	21.39±0.67	21.74±1
DO (mg l^{-1})	6.29±2.2	6.57±1.3	5.95±1	6.73±1.3	6.54±0.8	5.87±0.9	5.88±0.7
Conductivity (µS m^{-1})	0.58±0.1	0.58±0.1	0.19±0.04	0.18±0.04	0.18±0.04	0.17±0.04	0.19±0.4
Salinity (ppt)	0.31±0.07	0.31±0.06	0.098±0.02	0.096±0.02	0.093±0.02	0.096±0.02	0.098±0.02
pH	8.56±0.2	8.46±0.4	7.68±0.4	7.65±0.2	7.52±0.2	7.45±0.3	7.62±0.2
TDS (mg l^{-1})	0.41±0.09	0.41±0.08	0.13±0.02	0.12±0.02	0.15±0.1	0.12±0.02	0.13±0.02
TSS (mg l^{-1})	0.013±0.04	0.013±0.04	0.013±0.04	0.013±0.04	0.015±0.04	0.013±0.04	0.013±0.04
Phosphates (mg l^{-1})	0.38±0.2	0.41±0.2	0.25±0.2	0.16±0.1	0.2±0.2	0.19±0.2	0.27±0.2
Nitrates (mg l^{-1})	5.54±2.7	5.08±2.9	5.36±3.5	4.56±2.4	4.61±2.3	5.26±2.2	4.69±2.03
Chl-a (µg l^{-1})	0.076±0.04	0.17±0.4	0.097±0.06	0.091±0.05	0.097±0.03	0.092±0.42	0.131±0.14

3.2 Multivariate analysis

Four principal components accounted for 94.7 % of variation in the data and eigen values (shows degree of association) are shown in **Table 2**. The 1st, 2nd, 3rd and 4th principal components accounted for 43.2%, 24.2%,17.8% and 9.5% of the variation between the sites and the variables were: chlorophyll-a, conductivity, lake depth and dissolved oxygen respectively. 4.7% of the variation was explained by nitrates and KMO= 1 while Bartlett's test was not significant ($P>0.05$).

Table 2. Loading matrix of the water quality variables of *Lake Naivasha and Lake Oloiden*

Component number	Eigen value	Percentage of variance	Cumulative percentage
Chlorophyll-a	6.0	43.2	43.2
Conductivity	3.4	24.2	67.4
Lake depth	2.5	17.8	85.1
Dissolved oxygen	1.3	9.5	94.7
Nitrates	0.7	4.7	99.4
pH	0.09	0.611	100
Phosphates	$4.3E^{16}$	0	100
Salinity	$3.0E^{16}$	0	100
Secchi depth	$4.3E^{17}$	0	100
Total dissolved solids	$-2.8E^{17}$	0	100
Temperature	$-1.5E^{16}$	0	100
Total suspended solids	$2.6E^{16}$	0	100

The biplot of the first and second principle components showed that Lake Naivasha sites were closely linked by the following variables: secchi depth, depth, PH and salinity (characterized: Oseria and Korongo) (**Figure 2**). The characteristic that influenced the distinctness of Oloiden ST1 and ST2 was: chlorophyll-a which was linked to temperature, orthophosphates, nitrates, TDS and conductivity. Crescent site was distinguished by TSS while Malewa was distinguished by the DO (**Figure 3**). KMO <0.6 while Bartlett's test was significant (P<0.05).

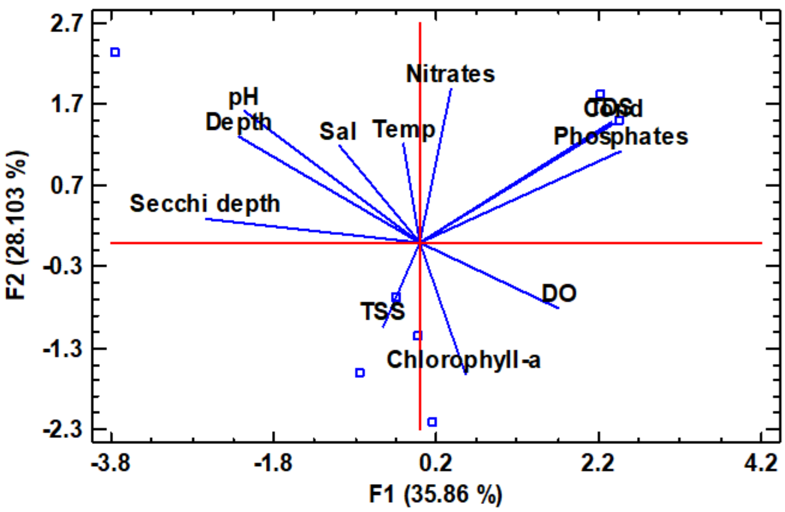

Figure 2. A correlation between various water quality parameters in the Lakes Naivasha and Oloiden study sites (PCA-1 and 2).

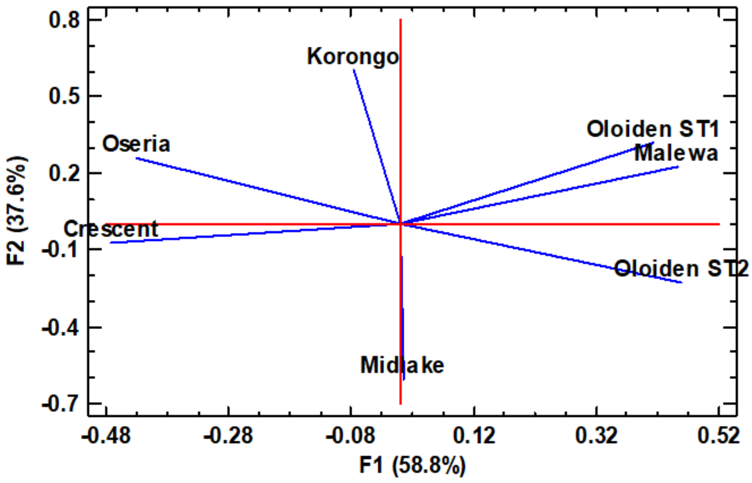

Figure 3. Correlation between the various study sites in the Lakes Oloiden and Naivasha.

The **Figure 4** displays the results of cluster analysis with division into 4 distinct regions (i) Lake Oloiden (Oloiden ST1 and ST2), (ii) midsection (Oseria, Korongo and Midlake), (iii) Malewa and (iv)Crescent.

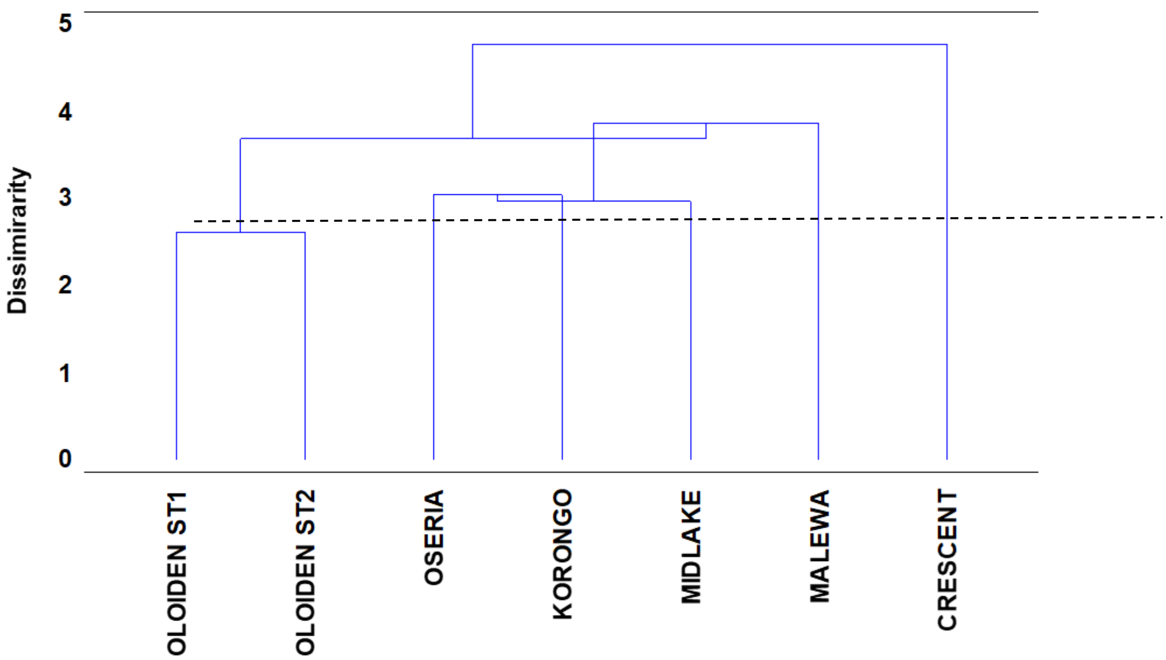

Figure 4. A cluster diagram of the study sites in the Lakes Naivasha and Oloiden (truncation is denoted by a dotted line, where togetherness means homogeneity).

4.0 DISCUSSION

4.1 Physical parameters

Two physical parameters were considered: lake depth and secchi depth. The lake depth has increased due to the increase in the water level (Hubble and Harper, 2002; Mavuti and Harper 2005). Crescent was the deepest part of Lake Naivasha while Malewa was the shallowest and this may be attributed to siltation (Mavuti and Harper, 2005). Also, Crescent had the highest secchi depth while Oloiden ST1 was the lowest followed by Malewa. The Secchi depth has increased as compared to previous and this indicates that the lake transparency has increased (Ballot *et al*., 2009; Obegi *et al*., 2021).

4.2 Physico-chemical parameter

The temperature was above 20 ^{o}C in all the sites studied and was within the range of previous Lake Naivasha findings. The Lake Oloiden had a significantly higher temperature as compared to the Lake Naivasha this could be attributed to the higher salinity. The DO was lower than previous findings in Lake Naivasha 7-9 mg/l). However, the dissolved oxygen did not vary with respect to the Lake Naivasha and Lake Oloiden (Ndungu *et al*., 2014).

The Lake Oloiden had a significantly high conductivity as compared to the Lake Naivasha. However, the conductivity of Lake Naivasha was much lower than its previous (251-421 µScm^{-1}), an indicator that the increase in water has caused a dilution (Ndungu *et al*., 2014). There was a significant difference in salinity between the Lake Oloiden and the Lake Naivasha. The PH tallied with previous findings in Lake Naivasha and was a little lower for the Lake Oloiden (previously, 9.3-9.9) (Ballot *et al*., 2009). The pH of Malewa was among the low and this may be attributed to influx of fresh water from River Malewa (Ndungu *et al*., 2014).

The total dissolved solids differed with the respective study sites and the highest were in Lake Oloiden sites (Oloiden ST1 and Oloiden ST2): influenced by mixing of saline and fresh water (Telesh and Khelebivich, 2010). The total suspended solids were within the range of previous findings in the Lake Naivasha (Ndungu *et al*., 2014). The water transparency is very important in determination of suitability of lake ecosystem since it affects primary productivity (Obegi *et al*.,2021).

In comparison with Ndungu *et al*., 2014 the phosphates had increased significantly and this may be attributed to the increase in the water level (due to the rainfall). An increase in the lake level allows chemical interactions between ecotones and littoral zones which changes in the rainy and dry season; this aids in accumulation of dissolved nutrients promoting productivity (Obegi *et al*., 2021). Lake Oloiden had a high phosphate level which may be due to surface runoff from neighborhood; cattle and goats herds watering and washing nearby (returning water with detergents) (Obegi *et al*.,2021). The nitrates were similar in the sites; although, higher as compared to previous findings in the Lake Naivasha (0.167-0.0247 mgl^{-1}) this may be linked to agricultural runoff from the catchment (Ndungu *et al*., 2014).

Chlorophyll-a concentration gives an average standing crop or an abundance of phytoplankton. There was no variation of chlorophyll-a between the stations studied. The nutrient level was high but the phytoplankton biomass (chlorophyll-a) biomass was low (Ndungu *et al*., 2013; Obegi *et al*., 2021). An inverse relationship between the chlorophyll-a and the water level was observed previously. Increase in water level may have a dilution effect and may prevent complete mixing; no resuspension of the nutrients (Ndungu *et al*., 2013).

4.2 Multivariate analysis

In correlating the chlorophyll-a and conductivity there was no much common variance found and the correlation matrix was not identical. On the other hand, correlating of various water quality variables that are site particular there were some sites with common variance and whose matrix was identical. The lake depth, pH and the salinity were characteristics associated with Oseria and Korongo. These sites are part of the Lake Naivasha and they could be having some similarities due to mixing (affects variables in a homogenous way) (Ndungu *et al*., 2014). The characteristic that influenced the distinctness of Oloiden ST2 and ST1 was chlorophyll-a which was linked to temperature, nitrates, orthophosphates, total dissolved solids and conductivity. Temperature is a major environmental variable that situate phytoplankton into context due to the direct effect on productivity (Suther and Rissik, 2008)). The presence of nutrients (phosphates and nitrates) and sunlight (affects temperature) has an effect on the primary productivity; chlorophyll-a (used in prediction of the phytoplankton biomass) (Obegi *et al*., 2021). Crescent was distinguished by total dissolved solids. Turbidity may be due to nutrients, chlorophyll-a and ionic presence (previously isolated, Crescent Lake (crater)) due to underlying volcanic rocks (Ndungu *et al*., 2014). Malewa site was distinguished by dissolved oxygen. This may be credited to the inflow River Malewa (Ndungu *et al*., 2014; Obegi *et al*., 2021).

The cluster analysis resulted in 4 groups: Lake Oloiden (Oloiden ST1 and Oloiden ST2) had particular high salinity and conductivity (an indication of a gradient between Lake Oloiden and Lake Naivasha). The water quality may affect productivity along the salinity gradient (where saline and fresh water meet) (Valsco *et al*., 2019; Obegi *et al*., 2021; Nyangau, 2021). The lake Naivasha's midsection sites (Oseria, Korongo and Midlake) were similar: pH, secchi depth, temperature, salinity, TSS and TDS. This was an indicator of high mixing level that may have been caused by wind. Crescent was dissimilar to the rest of the sites sampled because it's the deepest part of the lake, highest secchi depth, lowest conductivity, pH and TDS. It's of volcanic origin (crater lake) and the underlying ions may influence distinctness (Ndungu *et al*., 2014). Malewa was distinct and it had a low secchi depth (indicator of the turbidity) and a characteristic DO. Previous results indicated where a river inputs into a lake there exists a significant difference in the variables (Ndungu *et al*., 2014; Obegi *et al*., 2021).

5.0 CONCLUSION

The increase in the water level and the merging of saline and fresh water ecosystem led to the creation of a salinity gradient; an area were abiotic and biotic processes are non-linear. There was spatial temporal variation in water quality among the sites. Studying the variance in water quality in the Lake Naivasha and Lake Oloiden provided an insight about water quality status: associations between water quality variables. Grouping of sites aided in knowledge of similarity and dissimilarity of sites for effective aquatic management measures that are site particular.

6.0 ACKNOWLEDGEMENT

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