# Effects of Lake level changes on water quality and fisheries production of Lake Baringo, Kenya

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## Abstract

The study was conducted in Lake Baringo and determined quantitative relationships between water level changes, water quality, and fishery production for informed lake basin management. Long-term (2008 to 2020) data on water level, water quality, and fisheries yields from Lake Baringo were analyzed using a combination of statistical methods. Linear and waveform regression analyses described patterns of lake level fluctuations over time while, Pearson's correlation determined the concordance of lake level changes with water quality parameters, landings, and condition of fish species. PCA results grouped the study period into different years based on annual water quality variable levels. LOWESS analysis showed the decline of annual lake level amplitude over time with peak values in 1964 (8.6 m) and 2008 (9.4 m). The waveform regression significantly modeled lake level fluctuations as indexed by annual deviations from the long-term average (DLTM) and showed a 20-year oscillation between peak water levels in the lake. There were significant positive correlations of Water Level Fluctuations (WLFs) with water quality variables and water quality index (WQI) in Lake Baringo. Linear regression analyses showed a significant concordance ($p < 0.05$) between the annual fishery yield and the rising WLFs ($r = 0.66$). Overall, the results demonstrate that WLFs of Lake Baringo are a driver of fish species biomass and physico-chemical properties of the lake. We recommend the integration of fisheries yields, water quality assessment, and WLFs modeling at different temporal scales in the management of Afrotropical lake ecosystems

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# ABSTRACT

The study was conducted in Lake Baringo, a shallow rift valley lake in Kenya, and determined quantitative relationships between water level changes, water quality, and fishery production for informed lake basin management. Long-term (2008 to 2020) data on water level, water quality, and fisheries yields from Lake Baringo were analyzed using a combination of statistical methods. Linear and waveform regression analyses were used to describe patterns of lake level fluctuations over time while, Pearson's correlation was used to determine the concordance of lake level changes with water quality parameters, landings, and condition of fish species. PCA results grouped the study period into the years (2008 to 2012) marked by higher TP, turbidity levels, and Water Quality Index (WQI) values demonstrating the periods of poor water quality, and periods (2015 to 2020) of good water quality characterized by decreased TP, low turbidity and low WQI values attributed to higher annual lake water levels. Locally-weighted scatter plot smoother (LOWESS) analysis showed the annual lake level amplitude to have generally declined over time with peak values in 1964 (8.6 m) and 2008 (9.4 m). The waveform regression significantly modeled lake level fluctuations as indexed by annual deviations from the long-term average (DLTM) and showed a 20-year oscillation between peak water levels in the lake. The lake water quality increased during the years when DLTM values were [?] 2 m. There were significant positive correlations of Water Level Fluctuations (WLFs) with water quality variables (conductivity, depth, TP, $PO_4{}^{3-}$, DO, temperature, turbidity, $NO_2{}^{-}$, $NH_4{}^{+}$ and $NO_3{}^{-}$) and water quality index (WQI) in Lake Baringo indicating lake water quality deteriorated during lower water levels and improved during rising water levels. Linear regression analyses showed a significant concordance ($p < 0.05$) between the annual fishery yield and the rising WLFs ($r = 0.66$). Also, there was a significant ($p < 0.001$) relationship between the condition factor of the native species, *oreochromis niloticus baringoensis* , and the yearly lake level amplitude ($r = 0.69$) while, catches of the lungfish, *protopterus aethiopicus* and *Barbus intermedius,*showed a differing relationship with WLFs in the lake indicating species-specific influence of WLFs on catches from the lake. Overall, the results demonstrate that WLFs of Lake Baringo are a driver of fish species biomass and physico-chemical properties of the lake. We recommend the integration of fisheries yields, water quality assessment, and WLFs modeling at different temporal scales in the management of Afrotropical lake ecosystems.

Keywords: Fisheries, water quality parameters, waveform and Gaussian models, and watershed management.

# INTRODUCTION

Water level fluctuations in aquatic systems affect their physico-chemical properties, assemblage structures, ecosystem functions, and ecological services (Coops and Hosper, 2002). Water level changes in lakes can be caused by natural factors such as climatic variability (Bergonzini *et al* ., 2004; Gownaris *et al* ., 2015), human influences such as through damning abstraction (Evtimova and Donohue, 2014) and through climatic forcing leading to extreme variability in rainfall and drought conditions (Dudgeon et al., 2006). The changes in the lake water level may intern affect physico-chemical parameters through volume changes and productivity of the system through ecohydrological influences (Zalewski *et al* ., 1997; Coops and Hosper, 2002). The influence of water level variations on water quality and fisheries production has been widely studied in most temperate rivers, lakes, and reservoirs (Welcomme 1970; Hamerlynck *et al* ., 2011; Kolding *et al* ., 2016). However, there has been a paucity of studies in tropical freshwater bodies and especially the Afrotropical systems. Changes in water level fluctuations (WLFs) tend to affect lake productivity through nutrient supply variations, influence on breeding areas, and changes in shallow productive inshore areas (Kolding and van Zwieten, 2012; Gownaris *et al* ., 2015; Musinguzi *et al* ., 2019) in addition to changes in water quality parameters (White *et al* ., 2008).

The physico-chemical properties of water bodies play a significant role in various aspects of their ecohydrobiology (the relationship between hydrology and ecology) (Zalewski *et al* ., 1997). The interactions of physico-chemical properties of water have a significant role in the composition, distribution, and abundance of aquatic organisms (Hinckley*et al* ., 2014). Lake Baringo is a shallow freshwater rift valley lake in Kenya with a surface area of about 140 $km^2$ and designated as a Ramsar site (Ramsar, 2002). The lake is facing human-induced and natural stressors as a result of land and water use systems as well as climate variability, amongst others (Omondi *et al* ., 2014). Additionally, Lake Baringo is characterized by low water depths (average of 9.5 m, as in 2020, Walumona, personal observation), the mixing of surface and bottom water induced by the wave actions together with the clay soils of the catchment contributes to the lake's notable high turbidity, reported to affect the primary productivity of the lake (Hinckley *et al* ., 2014; Odada *et al.* , 2006; Nyakeya *et al.* , 2020). The lake has a long history of water level fluctuations (Hickley *et al* ., 2004; Aura *et al* ., 2020). Although there have been reports of the influence of these fluctuations on its fishery (Kallqvist, 1987; Omondi *et al* ., 2011), these have been mostly on an inter-annual or semi-annual basis and have not accounted for long-term inter-annual variability. Additionally, the lake water level changes are likely to affect physico-chemical parameter values, however, despite the periodic fluctuations in the water level of Lake Baringo, there are no accounts of how these fluctuations have affected its water quality parameters and ecological functions including, fisheries yields. In this study, we hypothesized that both intra- and inter-annual changes in the levels of Lake Baringo will affect the water quality parameters and fisheries, with cascading influences on lake functions and livelihoods.

## MATERIALS AND METHODS

### *Study area*

The study was conducted in Lake Baringo (Figure 1), a shallow (mean depth = ~ 9.5 m, Walumona, personal observation) freshwater lake in the eastern Rift Valley of Kenya. The lake lies at 0deg36'N, 36deg04'E, and approximately 60 km north of the equator at an altitude of 975 m above mean sea level. It is also a source of freshwater used for domestic purposes by the local population (especially for drinking), livestock and supports a substantial fishery in a semi-arid area. Its fishery has been reported to be poor and originally composed of five species. Three (*Oreochromis niloticus baringoensis* , *Clarias gariepinus* and *Protopterus aetiopicus* ) of species are of commercial value while, *Barbus spp.* now rarely appears in fisher's catches and *Labeo spp.* has almost disappeared in the lake (Aloo, 2002). The decreased fish diversity is thought to be due to overfishing pressures but could also be attributed to limnological changes (Hickley *et al* ., 2004).

The lake surface is reported to cover slightly over 130 km$^2$ with wide fluctuations as a consequence of water level fluctuations due to climatic influences (Kallqvist, 1987; Hickley*et al* ., 2004). The catchment area is about 6820 km$^2$ and includes a large part of the western escarpment of the Kenyan Rift Valley where most of the water is derived from.

The climate of the region is "semi-arid" characterized by two rainy seasons with an annual average of about 600 mm (Omondi *et al* ., 2014). Due to heavy rains experienced in 2011 in the Eastern African region, the lake water surface increased dramatically to 207 km$^2$ in 2016 (Obando *et al* ., 2016) and then to more than 250 km$^2$ in 2020. The dry season usually starts from September to February with no rain in January while, the rainy season occurs between March and August (Odada *et al.*,2006). The precipitation in the lake area 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 faces a very high annual evaporation rate of 1650-2300 mm (Odada *et al* ., 2006). The lake has no known outflow and is supplied by inflows from seasonal (Endao, Lokesen, Makutani, and Ol Arabe) and perrenial (Perkerra and Molo) rivers (Figure 1). Lake Baringo is believed to have an underground seepage that maintains its freshness by losing approximately 108 m$^3$yr $^{-1}$ (Dunkley *et al* ., 1993).

### *Data collection*

Lake water levels (WLs) data were obtained from the Kenya Water Resources Authority (WARA) for the period from 1956-2018. The water level is monitored by a graduated wooden scale of 5 m height with the nearest 1-cm accuracy. The scale was installed at the lowest elevation in the southern part of the lake (Figure 1) to enable monitoring even during low lake levels. Additional WL data were obtained by the project from January 2020 to April 2021 using a similar scale and the same location. For each year of record, both for the two periods (1956-2018) and ( 2020-2021), both monthly and yearly mean lake levels were calculated and used to derive the lake water level fluctuation (WLF) indices as described below. Both the water quality parameters and fish landings were measured from three ecological zones (northern, central, and southern) in the lake extending from the northern to the southern parts of the lake (Figure 1) in order to cover the entire lake area. The characteristics of the three ecological zones of Lake Baringo are described in Walumona *et al* . (2021). A total of 9 stations (N1, N2, N3, C1, C2, C3, S1, S2, and S3), three from each zone, were then selected in the three ecological zones of the lake for water quality sampling. Station replicates are numbered according to the three zones and are shown in Figure 1.

### *Water Level Fluctuations (WLFs) indices*

Two differently time-lagged indices were used as indicators of water level fluctuations in Lake Baringo as proposed by White *et al.*(2008): (1) the difference from the long-term mean (DLTM) (m) was calculated by determining the mean water level from 1956 to 2020 for the lake and then subtracting that mean value (across years) from the mean water level for a particular year. These calculations result in positive and negative values indicating the mean water level for a particular year relative to the lake's overall long-term mean. (2) the annual amplitude (WLamp, m) determined as the difference between the lowest and highest recorded lake level within a year (WLmax-WLmin) provides a measure of the strength of the flood pulse for that particular year.

### *Water quality parameters*

The following water quality parameters were measured in the lake: conductivity, turbidity, chlorophyll-a (Chl-a), depth, DO, temperature, TP, $PO_4^{3-}$, $NO_3^-$, TN, $SiO_4^{4-}$, $NH_4^+$. The data were collected monthly from the 9 stations from March 2008 to June 2019 and again from January 2020 to April 2021. Temperature, dissolved oxygen, and conductivity were measured *in situ* using a multiparametric field probe (YSI Incor.550, USA); turbidity with a turbidimeter (HACH 21000, Germany). The water depth at each sampling station was determined by an echo sounder (Plastimo Echotest II, 59588, France). Water samples for nutrients (TP, $PO_4^{3-}$, $NO_3^-$, TN, $SiO_4^{4-}$, and $NH_4^+$) and Chl-a analyses were taken at each station using a small 5-liter polyethylene canister, previously rinsed with distilled water. Before the nutrient analyses, water samples were filtered using Macherey-Nagel GF/5 filters with a porosity of 0.7 µm (Bartram and Ballance 1996). Both filtered water and labeled vials were placed in a portable freezer at 4°C and later stored in a fridge at -20 °C for further nutrient and chlorophyll-a analyses in the laboratory. Phosphate, Ammonium, Nitrites, Silica, and Chl-a were analyzed on filtered water using various standardized techniques of UV-Visible spectrophotometric analysis of water samples (APHA, 2005; Rodier, 2009). The laboratory details of sample analysis procedures are described in Walumona *et al* . (2021).

In order to evaluate how lake level changes may affect the water quality of the Lake, a water quality index (WQI) was derived (Bhateria and Jain, 2016). The WQI included the parameters given in Table I and was calculated as an indicator of water pollution in two steps using the Bhateria and Jain (2016) method.

1°) determination of a subjective water quality index by using k coefficient:

$$\mathrm{WQI}_{\mathrm{sub}} = k\frac{\sum_{i=0}^{n}\mathrm{Ci\ Pi}}{\sum_{i=0}^{n}\mathrm{Pi}}(1)$$

Where, $k$ is a subjective coefficient with a value ranging between 0.25 (mostly for heavily contaminated water indicated by blackish color, harsh odor, visible fermentation, etc.) and 1 (apparent contamination, clear or with natural suspended solids), $n$ is the total number of parameters, $Ci$ is the value assigned to parameter $i$ after normalization and $Pi$ is the relative weight assigned to each parameter with a value between 1 and 4, where 4 is assigned to a parameter that is most critical for the preservation of aquatic life (e.g. dissolved oxygen) and 1 is assigned to the parameter that has a less direct impact (e.g. temperature and pH) (Table I). Ci is a normalization factor, to make the WQI more objective and realistic (Herna'ndez-Romero *et al* ., 2004).

2°) Following normalization, an objective WQI was calculated using k = 1 in order to account only for variations due to the parameters measured in situ as:

$$\mathrm{WQI}_{\mathrm{obj}} = \frac{\sum_{i=0}^{n}\mathrm{Ci\ Pi}}{\sum_{i=0}^{n}\mathrm{Pi}}(2)$$

### *Fish landings*

Data on fish landings (1982-2018) from the lake were obtained from the monthly records of the Kenya Fisheries Department at Baringo Station and by sampling the landings from January 2020 to April 2021. The fish landings data represented catches from the entire lake and were derived from representative catches from the northern, central, and southern parts of the lake.

The data collected included weight (0.1 kg) and length (nearest mm) for each specimen of species landed randomly sampled from the fishers. The relative condition factor (Kn) was estimated for each species over the same period (2008-2020) from the ratio of observed weight to expected weight for length following Le Cren's equation (Le Cren, 1951).

### *Statistical analysis*

Principal components analysis (PCA) was used to group the years (2008-2020) based on physico-chemical variables and water level fluctuations. Linear regression (y = ax + c) and waveform sine regression (y = a*sin (2*p*x/b + c) analyses were performed to determine the best-fitting model to explain the patterns of lake level fluctuations (WLFs) over the years. Where both models were not significant, a Locally Weighted Scatter Plot Smoother (LOWESS, Cleveland, 1979) was used to describe the pattern of lake level fluctuations. LOWESS is based on a weighted least squares algorithm that gives local weights the most influence while minimizing the effects of outliers. A smoothness parameter (f) of 0.2 was found to adequately smooth the data without distorting the temporal patterns.

Pearson's correlation coefficient was used to determine the concordance between WLF indicators (DLTM and Amplitude, WLamp) and fisheries variables and with water quality parameters (conductivity, turbidity, chlorophyll-a, depth, DO, temperature, TP, $PO_4^{3-}$, $NO_3^-$, TN, $SiO_4^{4-}$, $NH_4^+$ and WQI). Both Pearson's and linear regression analyses were conducted on log (x + 1) transformed data to meet the required assumption of normality of the dataset (Zar, 2010). The frequency distribution displayed as a histogram of pixel depth was used to group the sampling period in years from 1956 to 2021 based on the increased or decreased rate of the depth while, the lake water level – lake surface area relationship was determined using a linear regression model.

Linear regression and non-linear Gaussian distribution (Zar, 2010) were used to determine the influence of WLFs on the lake's fishery yields and condition factor as a measure of growth. The Gaussian distribution follows a unimodal pattern and tested the hypothesis that the lake fisheries production and fish condition will correspond to optimum WLFs levels below and above which a decline is realized. All the graphical plots were implemented in the Sigma Plot software package.

## RESULTS

### *Temporal variation in lake properties*

The results of PCA ordination showed a clear separation between the years based on the lake water quality properties and fisheries yields for a 13-year time frame (Figure 2). Of the five axes extracted in the PCA, only axes 1 and 2 are presented as they explain the majority of the extracted variance, 93.84% in total, 81.25 %, and 12.59 %, respectively.

The years 2013 and 2014 ordinated in the upper left of the biplot and are characterized as having high TN concentrations and total fish yields while, the years from 2008 to 2012 are ordinated to the lower right and characterized by having higher turbidity concentrations ranging between 73.69-185 NTU, higher WQI values fluctuating between 860.19 and 1443.47, higher TP levels varying from 146.66 to 240.35 µg. $L^{-1}$indicating periods of poor water quality and high yearly water level fluctuations measured as yearly amplitude (1.56-9.36 m). Besides, the years 2015 to 2020 that were ordinated in the upper and lower left of the biplot are characterized by having higher DLTM, indicating an increase in the annual lake water levels relative to the long-term average. The other water quality parameters such as DO and temperature, known to affect assemblages and lake function, were not strong descriptors in the grouping of years using the first two components (Figure 2).

### *Water Level Fluctuation Patterns*

The lake water levels fluctuated by yearly amplitude (WLamp ± SD) of 2.25 ± 2.00 m from 1956 to 2020. Consequently, a LOWESS plot showed that the lake water level annual amplitude fluctuated during the period 1956 to 1975 and then decreased steadily up to its lowest level in 1989 ( amplitude = 0.1 m), with a subsequent increase to peak amplitude in 2008 (9.4, m) before a decreasing fluctuation between 2008 and 2021 (Figure 3). Linear regression analysis showed a non-significant ($p$ = 0.12) negative relationship between yearly amplitude and time while the waveform Sine 3 parameter modeled as Wlamp =2.328*sin (2*[?]*year/43.45+6.28) unlikely revealed a significant result () even though $p < 0.05$ but r2 = -0.64 indicating a poor fit than a horizontal line. The trends in water level fluctuations as measured by DLTM (Figure 4) were poorly explained by linear regression model ($p = 0.1229$, $r^2 = 0.059$). However, the waveform Sine (3 parameter) model: DLTM = 1.376*sin (2*[?]*year/(42.98 + 6.28)) was highly significant although with a weak fit (P < 0.0001, r2 = 0.21), and indicated peak rise in water levels after every  20 years (Figure 4).

The depth frequency plot (Figure 5a) showed that for 25% of the years (1956-2021), the average depth of the lake was about 2 m while, for 20% of the years, the average depth was 3 m. For less than 10% of the years, the mean depth of the lake reached 4 m. Additionally only for less than 5% of the years, the lake means depth ranged between 10-14 m during the period from 1956-2021. The lake depth-area relationship showed significant dependence ($R^2 = 0.74$) of the lake depth on its area (A, $km^2$) modeled as: depth = $0.179e^{0.019A}$; Figure 5b. Thus, in current conditions, a 1m increase in lake depth leads to a ~90 $km^2$ increase in lake area with likely influence on the riparian communities through overflows.

### *Relationship between lake level fluctuations (WLFs) and water quality parameters*

A significant correlation ($p < 0.01$) was found between nine water quality parameters (conductivity, depth, TP, $PO_4^{3-}$, WQI, DO, temperature, turbidity, and $NO_3^-$) and DLTM (Table II). Only, one parameter ($SiO_4^{4-}$) was significantly ($p < 0.01$) correlated with the yearly amplitude (WLamp) in Lake Baringo indicating the DLTM to be a better predictor of water quality in the lake at an inter-annual scale. Except for the depth and different forms of nitrogen ($NO_3^-$, $NO_2^-$ and $NH_4^+$) which had negative correlations with DLTM, other parameters demonstrated positive concordance with increasing DLTM over time in the lake. $NH_4^+$ that ranged from 21.75 to 48.8 µg $L^{-1}$, also showed significant negative correlation (r = -0.64, $p <$ 0.05) with DLTM over time in the lake.

Silicate ions ($SiO_4^{4-}$) ranged from 18.92 to 27.43 mg $L^{-1}$ across all years (2008-2021). $SiO_4^{4-}$ did not demonstrate a concordance with DLTM but showed a positive significant correlation with yearly amplitude of lake levels (r = 0.70, p = 0.008) indicating the ion is tracked by short-term changes in the lake. There was no significant concordance between Chl-a, and TN with any of the WLFs indices over time in the lake. The water quality index (WQI) as a measure of the lake water quality was significantly correlated with the DLTM (r = 0.80,$p$ = 0.001) and not the lake water level amplitude, WLamp (Table II). The Gaussian 4 parameter unimodal model further provided a significant fit ($p < 0.05$) to the relationship between WQI and DLTM ($R^2 = 0.89$) and not with the lake amplitude (Figure 6a and b) indicating that a range of DLTM of [?] 2 m and in the range of 6.5 to [?]10 m provided a good water quality of the lake as WQI approached the WHO recommended value of WQI [?] 100, while DTLM values of [?] 2 m resulted into poor water quality. The Gaussian, 4-parameter model: WQI = 314.68 + 1252.05*exp(-0.5*((x - 3.88)/2.2)2) yielded a significant relationship ($p$ = 0.0024 ) between WQI and DLTM (R2 = 0.89) (Figure 6). These results indicated that the water quality index (WQI) was lowest in years closest to the highest long-term mean (DLTM = 9.9 m) and increased with decreasing lake water levels.

### *Relationship between lake level fluctuations and fisheries*

The reported yield of Lake Baringo's fisheries has fluctuated greatly since the early 1980's. Annual yields from 1982-2020 (years of available data on annual fisheries) ranged from approximately 8 metric tons in

1994 to 496 metric tons in 2017 averaging close to 227 metric tons per year (Figure 7). Linear regression analysis showed a significant relationship ($p < 0.05$) between annual fisheries yields and the WLs (amplitude) indicating the direct effect of WLFs on the lake's fisheries production (Fishery yield = 78.15 + (29.94 * WLS); R2 = 0.66; Figure 7). These results suggest that water level changes have an influence on fish catchability in the lake.

The fishery variables (fish yields and fish condition factor) were correlated with the WLFs indicators as per the Pearson's correlation coefficients (r) shown in Table III. The results indicated a strong significant positive relationship ($p < 0.001$) between the condition factor of the endemic tilapia species, *Oreochromis niloticus baringoensis* , with the yearly lake water level amplitude (r = 0.69). However, there were potential significant correlations (r =  0.5) between the condition factor of the lungfish, *Protopterus aethiopicus* with DLTM (r = 0.48), and between the annual yield of the barb, *Barbus intermedius,* and DLTM (r = 0.50) (Table III). These results demonstrated positive and negative relationships for *P. aethiopicus* and *B. intermedius* with mean WLFs,respectively. There were no significant relationships between either DLTM or amplitude (WLFs) and total biomass as well as with fish species yields in the lake except for *B. intermedius* (Table III).

## DISCUSSION

The results demonstrated inter-annual water level changes in Lake Baringo and the existence of patterns across years for the long-term database (1956-2020). They also indicated a near two decades periodicity or oscillation in extreme peak water levels across a 64-year time frame. This oscillation is likely associated with periodicity in abnormal rainfall events due to climate cycle variability in the lake watershed over time (Ngaira 2006; Aur *et al.,* 2020). The mean annual WLs and amplitude intensities have been fluctuating in the Lake Baringo watershed over the last six decades as also evidenced in other African lakes (Kolding and Van Zwieten, 2012) and elsewhere (Blenckner, 2005; Neckles, *et al* ., 1990; White *et al.,* 2008). The annual fluctuations are characterized by variable water quality changes ranging from poor to good water quality years with resultant impacts on lake ecology (Hickley *et al* ., 2004) and livelihoods (Aura *et al* ., 2020). In the long-term, the lake level has fluctuated from a low of 1.47 m in 1956 to peak levels (13.95, m) in 2017.

The results showed relations between WLF indices and lake water quality variables and with lake fisheries yields over time. These relations suggest a significant influence of water level fluctuations in the ecological functions of the lake. The results also indicated the impact of hydrological variable changes on the lake's fisheries productivity through some mechanisms related to water-level mediated changes in fish species catchability and condition factor as also reported for Lake Turkana in Kenya (Kolding *et al* ., 1993a) and elsewhere (Kolding*et al* ., 2012). Studies on concordance between lake WLFs and biota conducted elsewhere (Neckles, *et al.,* 1990; White *et al.,*2008; Gownaris *et al* ., 2015) showed similar patterns between WLFs and biota variables demonstrating the important role of water levels in a lakes' habitat availability, macroinvertebrates' richness and their temporal distribution.

The concordance of water quality variables with WLFs is expected as water levels are directly controlled by hydrological inputs driven by severe droughts and floods in the region. A rise or draw-down estimated at 1 m in water level causes a shift in the lake's hydrological budget that might affect the ecological process in the lake. The relationship between water level (WL) and the lake surface area indicated that a 1 m increase in water level leads to about 90 $km^2$ change in Lake Baringo's surface area. This finding is a demonstration that high water levels create flood pulse regimes that provide enhanced habitat, food, and breeding areas for fish species that contribute to increased fisheries yields (Gownaris *et al* ., 2015). The littoral habitat area is important for enhanced fisheries production in semi-arid lakes such as Baringo. For instance, in Lake Baringo, the lake level decline leads to large losses of the open water habitat thereby likely reducing the carrying capacity of species that dominate its pelagic zone. Moreover, the lake level decline shrinks the floodplain area and leads to losses of littoral habitats, feeding and breeding habitats of some species (Karenge and Kolding, 1995; Grown *et al* ., 2015; Mageria and Kibwage, 2009). This might probably be the reason for the low catchability of some commercially valuable fishery species (e.g.*O. niloticus barinoensis* and *B. intermediens* ) of Lake Baringo during the years of lower levels in the lake (Mlewa *et al* ., 2005; Nyakeya *et* *al* ., 2020). In Lake Turkana, Kenya, the majority of the lake's endemic species are found below the 10-m contour indicating that declines in inshore and offshore habitats would have severe ecological consequences for these species (Hopson, 1982).

The effect of WLFs on habitat variations and their effects on the fisheries of Lake Baringo is also a function of the depth of the lake and human population density settlements around the lake. The three zones of study (north, central, and south) in the lake will be differently affected depending on their depths and the human activities along the shores (Welcomme, 2008). Therefore as a result of changes in lake level, there is increased interaction between the aquatic and terrestrial ecotones during the rising water level years requiring an integrated approach to the management of the lake-terrestrial ecosystems. Regression and Gaussian analyses outputs demonstrated the highly responsive nature of turbidity and WQI to increasing DLTM indicating that hydrological indices are the major drivers of the water quality changes in the lake. We found positive correlations between nutrient components and WLFs except nitrogen forms ($NO_2^-$, $NO_3^-$, $NH_4^+$) and Chl-a which either showed negative relation with WLFS or did not demonstrate any relationship (TN and Chl-a) with any WLFs indices due probably to the decrease of these nutrient concentrations and increase of Chl-a levels with the increased DLTM in the lake. These results are in agreement with the findings from most tropical reservoirs and lakes. For example, in Lake Tana, Ethiopia, the plant nutrients are quickly exhausted during draw-downs and their effects on biological production become less important (Karengea and Kolding, 1995). The results of this study also indicated that the years with decreased WLs were characterized by lower lake primary production measured as chlorophyll-a concentrations indicating the effect of WLFs on the lake production in terms of phytoplankton biomass and likely the reported zooplankton limitation in Lake Baringo (Schagerl and Oduor, 2003; Tarras-Wahlberg *et al* ., 2003).

## CONCLUSION

The results of the study highlight the link between water quality properties and WLFs in Lake Baringo. The lake's fishery yields and species condition factors appear to be also influenced by WL changes. These linkages result from the influence of WLFs indices on the critical water quality parameters like turbidity, DO, conductivity, temperature, and the water quality index WQI). There is a direct link between years of high lake level and increased fisheries landings perhaps mediated through increased habitat availability as nursery and feeding grounds for species.

During periods of droughts with less inflow, water level decrease leads to a decline in littoral habitat due to the water volume reduction and this might force the species including juveniles to find a refugee in open water habitat enhancing the predatory degree and reducing the refugia areas in the lake for juveniles and some species (eg.*Oreochromis niloticus baringoensis* ). If the water level declines severely, the lake's physio-chemical characteristics will be altered with an eventual reduction in DO due to the decrease of the euphotic zone in the lake, increase in water temperature, and high conductivity making the conditions in the lake harmful for the aquatic communities. This emphasizes the need for long-term monitoring of the lake's condition and catchment for purposes of integrated lake management. Such management will require monitoring of upstream developments in order to maintain natural inflows during draw-down seasons.

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DATA AVAIL ABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.