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Characteristic Relationships between Phosphorous Accrual, Ecosystem Aspects and Water Level Fluctuations in Tropical Lakes: Naivasha Ramsar Site, Kenya

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Abstract

Hydrological dynamics affect water levels and thus affecting ecosystem structure and functions. Lake levels in tropical ecosystems affect phosphorous input through runoff from adjacent watersheds. The resultant biological community, water and sediment quality of the lakes due to water level changes is a reflection of the geology of the area and the anthropogenic activities in the watershed. The study conducted between January 2018 and December 2019 was to explore relationships between the phosphorous input and Water Level Fluctuations (WLF) recorded by Water Resource Authority (WRA). Lake water samples were analyzed in the laboratory for phosphorous using molybdenum blue-ascorbic method and recorded using spectrophotometer. Chlorophyll- *a* was determined by extracting a filtered sample with 15 ml acetone and incubating overnight and thereafter read using a double beam spectrophotometer. Total Suspended Solids (TSS) was determined by filtering 200 ml of a water sample and dried overnight at 105˚C. The lowest and highest phosphorous concentrations recorded were 0.2 mg/l and 0.42 mg/l at NST7 and NST2, respectively. Measurements of Chlorophyll- *a* were 0.32 mg/l and 0.42 mg/l at NST9 and NST2, respectively. Secchi transparency measurements were 32.9 cm at NST3 and 84 cm at NST1. The highest and lowest TSS concentrations were 0.14 mg/l and 0.13 mg/l at NTS1 and NST8, respectively. The hydrodynamic regime in most tropical lakes plays a significant role in the re-reaction of phosphorous that consequently influences productivity. Tropical lakes have extreme lake level fluctuations which accelerate the production process. The influence of water level changes on aquatic productivity is crucial in most tropical lakes and should be taken into consideration when assessing the environmental impacts.

Keywords

Lake Level Fluctuations, Total Phosphorous, Ecosystem Aspects, Lake Naivasha

1. Introduction

Lacustrine systems worldwide provide diverse functions for aquatic biota. Lake Naivasha as a ramsar site has experienced WLF over years. Lake level fluctuations are often driven by human activities and climate change which mostly affect Phosphorous loading. Increasing phosphorous accumulation in Lakes is an indication of increasing eutrophication (Stoof-Leichsenring et al., 2011). In most tropical lakes and reservoirs water levels and nutrient enrichment enhance their productivity and ecosystem functioning (Bot & Colijn, 1996; Mavuti, Moreau, & Munyandorero, 1996b). WLF is quite important in nutrient regeneration in the riparian land. The shallow area of a lake is believed to be the main sink of nutrients which are usually released during high water levels (Jones & Lee, 1982; Gownaris et al., 2018). In addition, nutrient input may enter the lake through agricultural, municipal and industrial runoff (Gaudet & Muthuri, 1981; Gaudet & Melack, 1981). Phosphorous attached to substrates on the littoral zone is released into the water column during biogeochemical reactions (Gaudet, 2014; Gaudet, 1979; Gaudet, 1977; Melack, 1979). The lake also experiences dry seasons and as a result shallow areas are exposed, the bare soil is enriched by the animal dung as well as use of fertilizers by small scale farmers. A rise in water level results in the release of large amounts of nutrients from the submerged plants and covered wastes (Gaudet & Muthuri, 1981; Howard-Williams & Lenton, 1975; Mclachlan, 1971) and that promotes phytoplankton biomass.

Chlorophyll-*a* concentration across trophic gradient of lakes is normally used to predict phytoplankton biomass (Gikuma-Njuru & Hecky, 2005). Nitrogen and phosphorous play a huge role in determining the maximum algal biomass reaching in a water body (Hecky & Kling, 1981). When the load of phosphorous, which is a limiting nutrient for algal growth is decreased, a decrease in maximum algal biomass is likely to occur (Jones & Lee, 1982).

This enrichment of phosphorous and presence of light predicts the algal growth in the lake, although in tropical lakes nitrogen depletion may occur and thus reduce algal productivity (Kalff, 1983; Richardson, 1985; Moed & Hallegraeff, 1978; Mavuti et al., 1996b; Lee & Jones, 1980). Tropical lakes accumulate higher concentrations of phosphorous than the temperate zones (Kitaka et al., 2002). Various studies (Talling, 2001; Pacini et al., 2018; Kalff, 1983) have shown that Lake Naivasha usually has higher levels of phosphorous than nitrogen. A study undertaken on the trophic state of the River Malewa flowing into the lake (Kitaka, Harper, & Mavuti, 2002) showed that the seasonal rainfall patterns are responsible for the changes in lake levels. Studies by Zwieten et al. (2011) noted that water level fluctuations of many freshwater ecosystems influence the ecology which in turn influences their productivity (Richardson & Heilmann, 1995; Kolding & Zwieten, 2012). According to Kilham (1990), when the water level increases, chemical interactions between ecotones occur. Littoral zone changes, occurring during the rainy and dry seasons, leading to the accumulation and dissolving of nutrients thus enhancing productivity (Talling, 1992; Kalff & Brumelis, 1993; Junk et al., 1989). Several studies have shown that accumulation of total phosphorous in the lakes contributes to phytoplankton biomass and sustainability of other aquatic flora and fauna (Kalffi, 1986; Hickley et al., 2002).

Water transparency provides an important characteristic in many tropical lakes and is frequently used to determine the suitability of lake ecosystems (Chapman, 1996). The clarity of tropical lakes, specifically Lake Naivasha, is normally reduced by incoming sewage wastes, runoff from heavy rain which carries suspended materials, sediments and microscopic organisms which can be measured as (TSS). Increased turbidity leads to growth of submerged microphytes (Briton et al., 2007). A high rate of sediment accumulation from increased human activity in the catchment influences the status of water quality (Krienitz et al., 2013; Stoof-leichsenring, 2011). The effect of reduced water transparency on light penetration has been shown by (Roach & Winemiller, 2014; Stoof-leichsenring et al., 2012).

Although most studies have investigated the effects of WLF in tropical lakes (Odongo et al. 2015; Kolding et al., 2016), there are some knowledge gaps on the relationships of such fluctuations with phosphorous input, as well as on the water clarity and Chlorophyll-*a* concentration in enhancing productivity. Lake Naivasha being a shallow ephemeral lake, fluctuations are driven by rainfall patterns, consequently making it dynamic both in its ecology and species diversity (Pacini et al., 2018). Other studies (Hubble & Harper, 2002; Harper, 1990; Becht et al., 2002) have shown that the lake is well mixed by wind currents and stratification occurs only in NST1 (**Figure 1**). This paper presents an investigation of the correlations between phosphorous concentrations, Chlorophyll-*a* concentrations and Secchi transparency in Lake Naivasha**.**

2. Methods and Materials

2.1. Study Area

Lake Naivasha is located in the eastern rift valley of Kenya 0˚46' S and 36˚20 E at an altitude of 1890 above sea level (Mavuti et al., 1996a; Mavuti & Harper, 2006). The lake has a catchment area of 3200 Km^2 and a surface area that varies between 130 Km^2 - 160 Km^2 during the dry and wet seasons respectively. For many years, the mean depth of the lake has been between 4 metres and 6 metres and surrounded by a belt of papyrus (Hickley et al., 2008). Lake Naivasha is the second largest wetland of international importance (Ramsar site) designated in 1995 (Secretariat, 2013) and has two other sister smaller lakes Oloidien and Sonachi crater. The closed basin (**Figure 1**) with only an underground seepage (Gaudet & Muthuri, 1981; Becht & Harper, 2002) without any outlet has remained fresh despite pressures from catchment, the human settlement and horticultural farming. The lake's physicochemical characteristics recorded pH values ranging 7.5 - 8.5, Dissolved Oxygen ranges between 7 mg/l - 9 mg/l and temperatures ranging from 20˚C - 25˚C. Lake Naivasha receives water from ephemeral streams where 90% comes from River Malewa draining from Nyandarua mountains with an area of 1730 Km^2 and River Gilgil from North with an area of 420 km^2 (Harper, Oxon, & Mavuti, 1990). The Lake is divided into four parts, three of which are partly connected; the crescent island which is the deepest (approximately 9 m), the main Lake which covers an area of 150 km^2 and to the east side of the Lake is Lake Oloidien which is approximately 5.5 km^2. The Crater Lake (Sonachi) to the west of the main Lake is isolated from the rest and covers about 0.2 km^2 (**Figure 1**).

2.2. Study Map

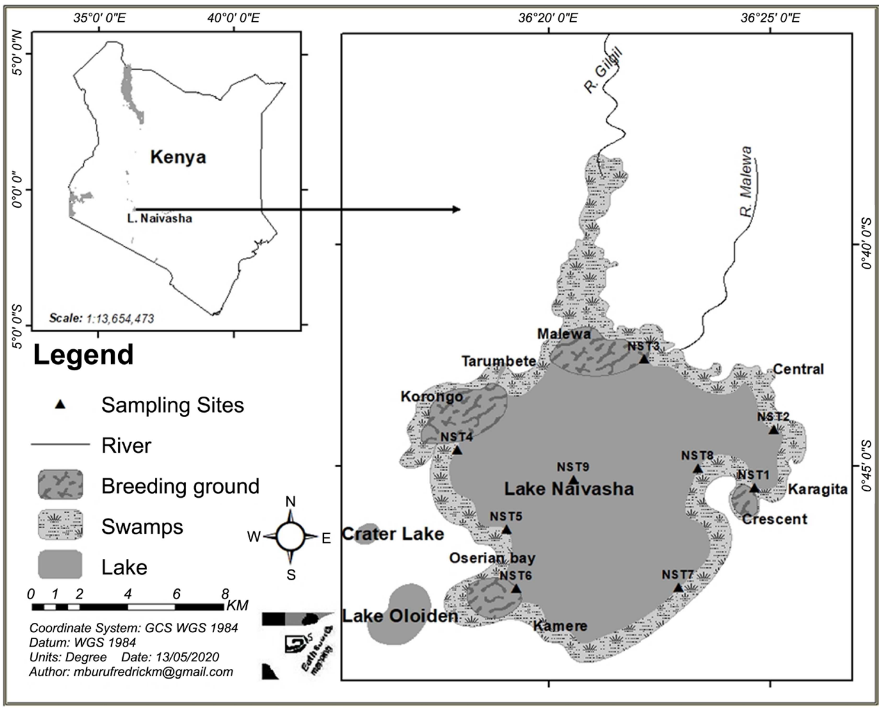


Figure 1. Location Lake Naivasha showing the 9 sampling points.

2.3. Sampling Design

An ecological survey design was adopted for the determination of phosphorus and chlorophyll- *a* concentration. Nine sampling points were selected (**Figure 1**) and duplicate water samples taken in at each of the stations. The water was collected from just below the surface of the lake using 1 L High Density Propylene plastic sample bottles. A portion of the water sample was immediately filtered using an acid-washed 60 ml disposable syringe to push the water through a pre-washed GF/C glass fibre filtered (whatman). The bottles containing the filtered and unfiltered samples were transported in a cool box and analyzed in the laboratory within 1 - 3 hours from the time of collection. Water transparency was measured *in situ* concurrent with the water samples collections. A Secchi disc (diameter 23 cm) was used to determine the transparency, according to (Bledzki, 2009) the procedure of water samples collection and transparency estimations were repeated monthly from October 2018 to October 2019. Lake levels data was recorded daily by the regional Water Resource Authority (WRA) in Naivasha.

2.4. Sample Analysis

Chlorophyll-*a* was determined by extracting a sample with 90% acetone after filtering 200 ml volume of water sample using Whatman filter paper of 0.47 μm diameter. Extraction was done by incubating the soaked sample in 15 ml of 90% acetone. The absorbance was then recorded by a double beam spectrophotometer at 630 nm, 647 nm, 664 nm and 750 nm which was used as a blank. Total Phosphorous was determined with molybdenum blue-ascorbic method (APHA, 2005), 50 ml duplicated samples were digested with persulphate. The colour development was advanced on the sample and the absorbance was read after 30 minutes to one hour at 880 nm wavelength using a double beam spectrophotometer in 1 cm cuvettes. A standard calibration was used to calculate the total phosphorus. Total suspended solids (TSS) were determined by filtering 200 ml of water sample using a pre-dried and weighed filter paper of 0.47 μm of diameter. The filtered sample was dried overnight at a temperature of 105˚C. The TSS levels were estimated by calculating the difference between the blank filter paper and the dried sample.

2.5. Data Analysis

Temporal trends in the lake levels, and phosphorus concentration were analyzed. A correlation analysis was conducted to determine the interrelationships among the lake levels, phosphorus levels, Chlorophyll-*a* and other water quality aspects.

3. Results

3.1. Lake Levels

The study revealed lake level fluctuations in 2018 decreasing in January to march, but increased sharply from April to July and continued decreasing up to April 2019 as shown in **Figure 2**. The highest observed lake level was 1889 m.asl in 2013, while the lowest level was 1887.5 m.a.s.l. in February and March 2018 while the highest was 1889.5 in July 2018.

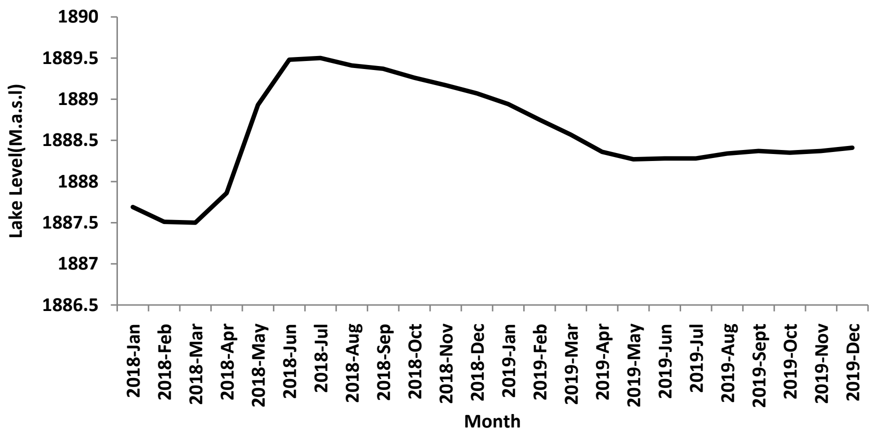


Figure 2. Shows water level changes in Lake Naivasha and monthly water levels from October 2018-2019. (Source: Water Resource Authority).

3.2. Phosphorus Levels and Lake Levels

From January to December 2018, results showed the highest phosphorous level in the month of June 0.42 mg/l corresponding with lake level of 1889.48 m.a.s.l. (**Figure 3**). The lowest phosphorus concentration (0.20 mg/l) was in the month of February corresponding with lake level of 1887.51 m.a.s.l. 2019 was slightly different 2018, the highest phosphorous concentration 0.42mg/l in the month of February, corresponding to 1887.5 m.a.s.l. and the lowest was January (0.33 mg/l) at lake level of 1887.51 m.a.s.l.

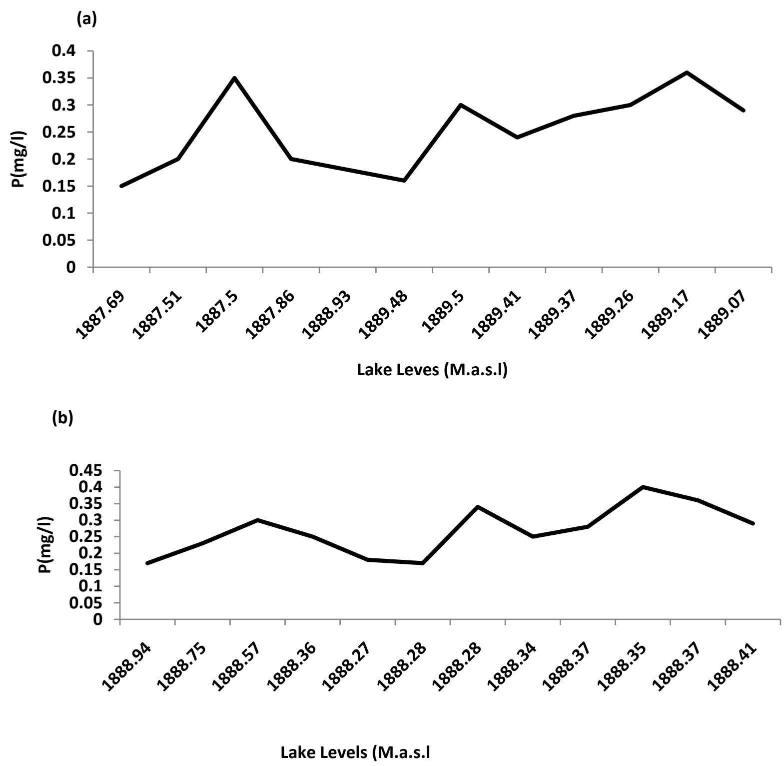


Figure 3. Lake level and phosphorus concentration relationship (a) January to December 2018 and (b) January to December 2019.

3.3. Mean Values of Phosphorous and Some Water Quality Aspects

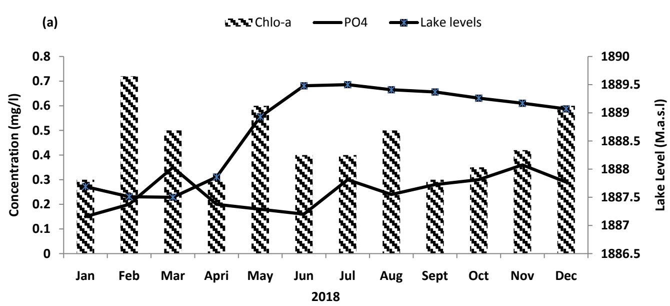
Descriptive analysis (**Table 1**) revealed higher mean (± SD) values of Chlorophyll *a* and phosphorous in NST2 with 0.42 ± 0.05 mg·l^{-1} and 0.42 ± 0.016 mg·l^{-1} respectively, while the lowest values were in NST9 for (Chlorophyll *a*) with 0.32 ± 0.009 mg·l^{-1} and NST5 for (phosphorous) with and 0.20 ± 0.016 mg·l^{-1}. Mean Secchi transparency recorded the highest measurement in NST1 with 84 ± 1.5 cm and the lowest in NST3 32.2 ± 0.4 cm. The highest mean TSS was recorded in NST1 with 0.144 ± 0.004 g·l^{-1} and lowest in NST8 with 0.134 ± 0.0028 g·l^{-1}.

Table 1. Mean values of phosphorous and some water quality aspects in the two year study 2018 and 2019.

STN	Chlo- (mg/l)	*P* (mg/l)	Sech (cm)	Tss (g/l)
NST1	0.39 ± 0.02	0.24 ± 0.007	84 ± 1.5	0.144 ± 0.004
NST2	0.42 ± 0.05	0.42 ± 0.004	43.7 ± 12	0.135 ± 0.003
NST3	0.39 ± 0.02	0.21 ± 0.008	32.2 ± 0.4	0.14 ± 0.003
NST4	0.35 ± 0.02	0.24 ± 0.002	44.5 ± 1.87	0.138 ± 0.002
NST5	0.33 ± 0.008	0.20 ± 0.016	40.07 ± 1.79	0.138 ± 0.003
NST6	0.32 ± 0.005	0.27 ± 0.008	34.8 ± 0.4	0.137 ± 0.0029
NST7	0.33 ± 0.007	0.206 ± 0.001	34.05 ± 1.4	0.136 ± 0.029
NST8	0.32 ± 0.007	0.24 ± 0.0.004	35.4 ± 0.4	0.134 ± 0.0028
NST9	0.32 ± 0.0009	0.24 ± 0.009	44.8 ± 1.76	0.140 ± 0.003

3.4. Relationship between Lake Levels with Chlorophyll *a*, and *Phosphorous*

The results revealed a sharp increase in Chlorophyll-*a* with increasing water levels from the month of March until June, whereas a decrease in Chlorophyll-*a* with increasing water levels from July to December 2018. The phosphorous insignificantly increased in June and September, and decreased in other months. Chlorophyll-*a* values increased as the lake level increases while phosphorous showed insignificant increase (**Figure 4(a)**). In 2019 a sharp decrease was observed in chlorophyll-*a* with increasing water Levels from the month of January and continued to July, where there was a slight increase in chlorophyll a until the month December (**Figure 4(b)**). Water levels increased from January to May followed by a decline in June and July in 2018 (**Figure 4(a)**). The lake water levels were highest in the period October to December and lowest in the month of September 2019 (**Figure 4(b)**).



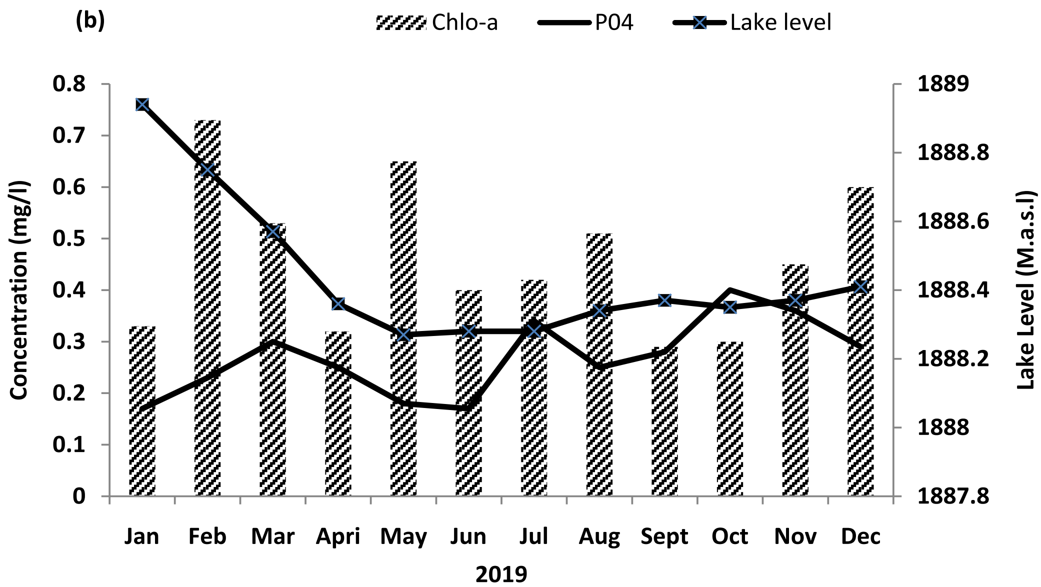


Figure 4. Relationships between the concentrations of chlorophyll *a*, phosphorous and water levels from January to December (a) 2018 and (b) 2019 at Lake Naivasha, Kenya.

3.5. Chlorophyll (*a*) and Phosphorous Correlations with Lake Levels

In 2018, Lake water level fluctuations had an insignificant correlation with chlorophyll (Figure 5(a); R = −0.183, R^2 = 0.335 $P > 0.005$ and N = 12). The correlation was slightly better when Lake levels and phosphorous were correlated (Figure 5(b); R = 0.218, R^2 = 0.0475). Just like in 2018, the correlation between water levels and chlorophyll-*a* was weak (Figure 5(c); R = 0.121, R^2 = 0.0206, $P > 0.05$ and N = 12) for the 2019. Similar observations were made when Lake levels and phosphorous were correlated (Figure 5(d); R = 0.028, R^2 = 0.0008).

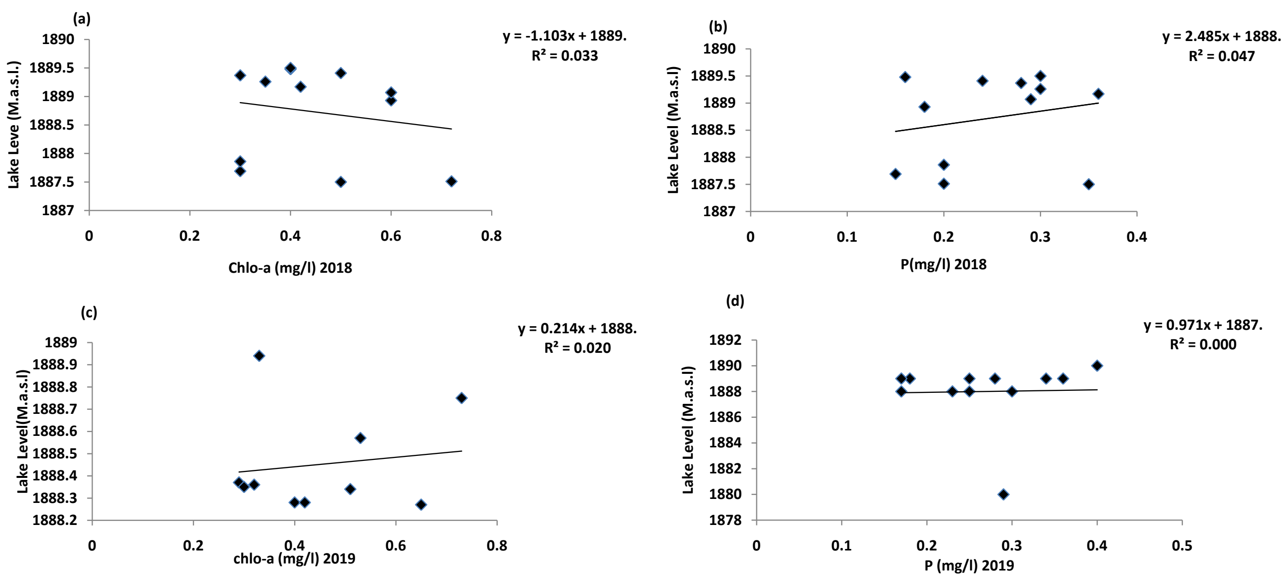
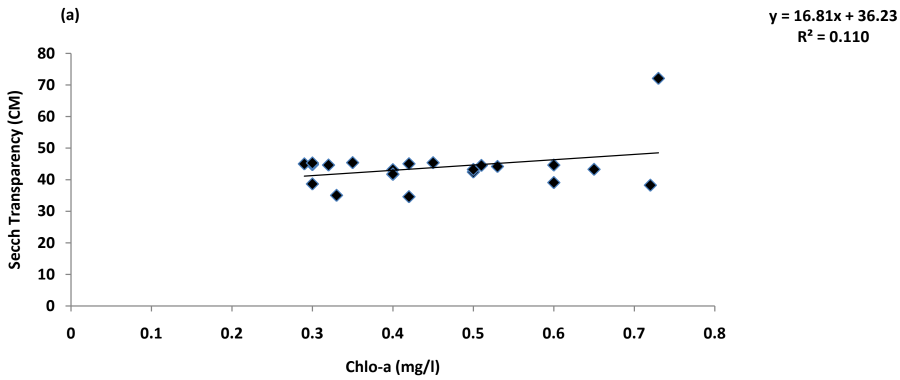


Figure 5. The correlation of lake levels with both chlorophyll *a* and phosphorous (a & b 2018), (correlations b & d 2019) in Lake Naivasha; a in 2018, b in 2019.

3.6. Secchi Transparency Correlations with Chlorophyll-*a* and Lake Levels

A positive correlation was also observed between Secchi transparency and Chlorophyll a (R = 0.334, R^2 = 0.1105; Figure 6(a)). There was slightly a positive correlation between the water levels and secchi transparency (R = 0.102, R^2 = 0.0103 $P > 0.05$ and N = 24; Figure 6(b)).



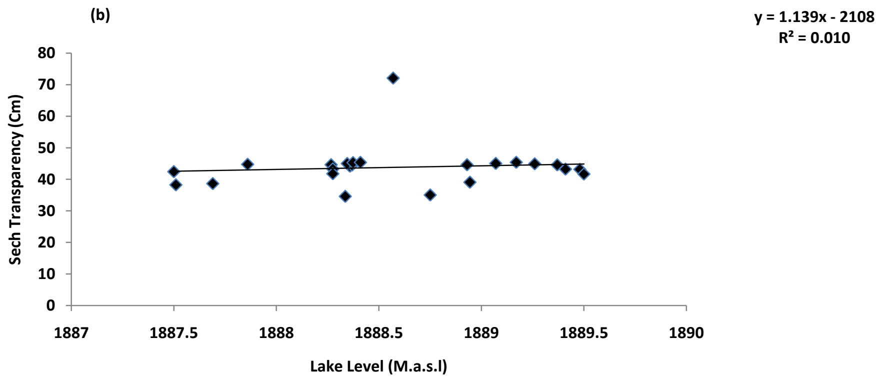
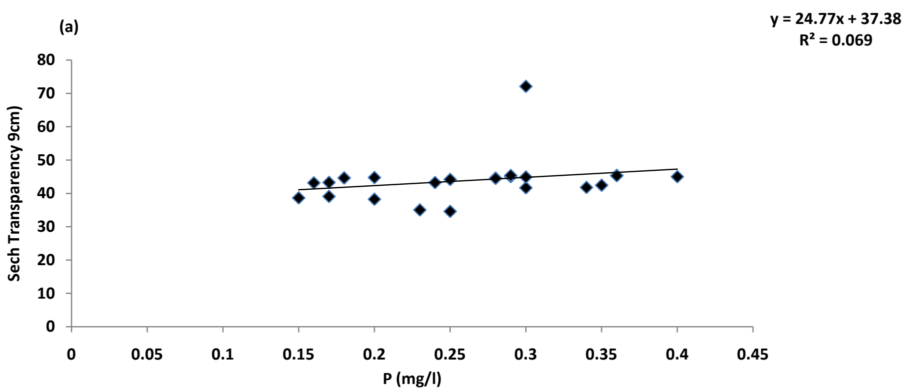


Figure 6. The correlation between secchi transparency with chlorophyll *a* and lake levels at Lake Naivasha, Kenya.

3.7. Secchi Transparency Correlations with Phosphorous and TSS

A positive correlation between Secchi Transparency and Phosphorous was observed (R = 0.264, R^2 = 0.0697; Figure 7(a)), while correlation between Secchi transparency and TSS is R = 0.156 R^2 = 0.0243; Figure 7(b).



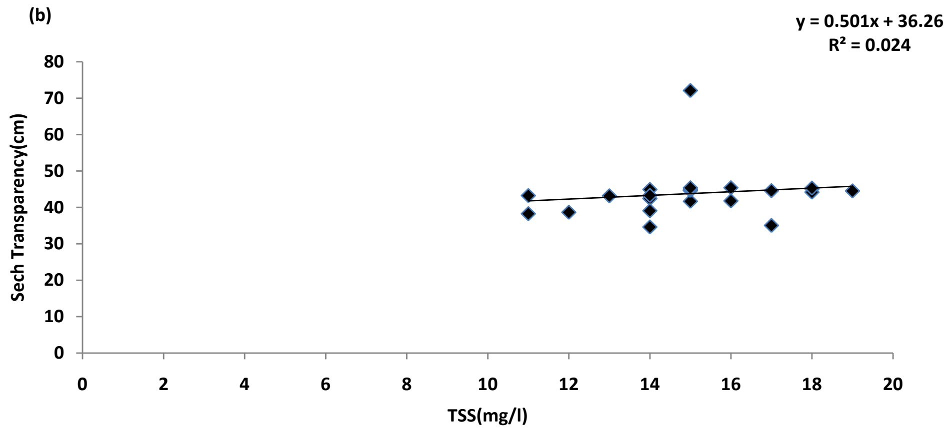


Figure 7. Correlations between TSS, phosphorous and secchi transparency at Lake Naivasha, Kenya.

3.8. Correlations between Chlorophyll-*a* and TSS

A strong positive correlation was observed between Chlorophyll-*a* and TSS (R = 0.142; R^2 = 0.0202; Figure 8) below.

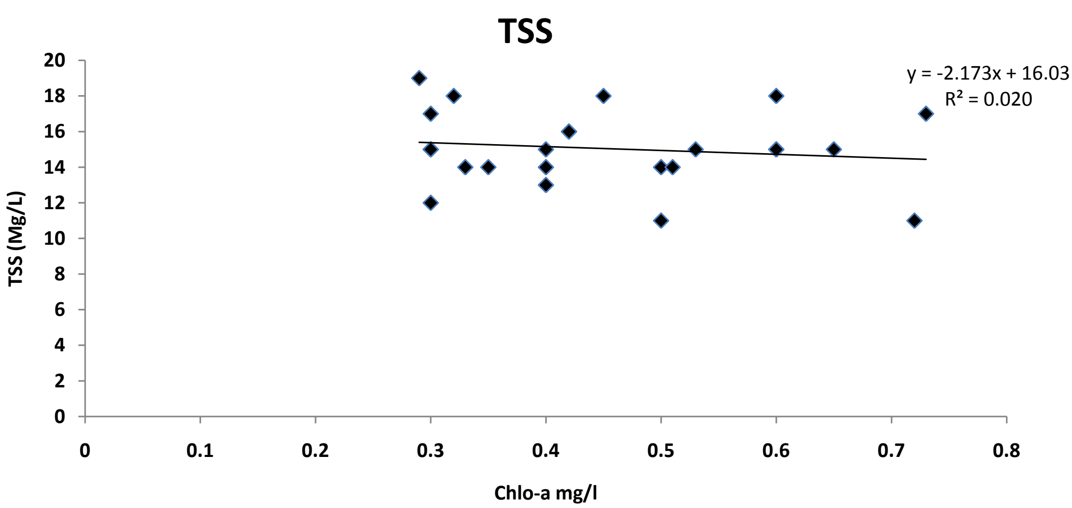


Figure 8. Correlation between chlorophyll *a* and total dissolved solids at Lake Naivasha, Kenya.

4. Discussion and Conclusion

Studies show that stratified Africa Lakes have reported that 90% of incoming phosphorous is stored in sediments and thereafter released or availed for phytoplankton (*chlorophyll-a*) production (Zwieten et al., 2011; Lee & Jones, 1980). Chlorophyll-*a* changes in most tropics shallow lakes are related to the cyclic aspects of water levels. Our findings indicated that phosphorous concentrations influence the levels of Chlorophyll-*a*. Increased phosphorous can be associated with availability of benthic fish (Chorus & Bartram, 1999) which helps in re-suspension of sediments leading to mobilization rates of sediment in shallow lakes but not in deep lakes.

These findings are consistent with those from related studies that showed that changes in Chlorophyll-*a* concentrations are usually associated with nutrient supply (Benndorf & Klaus, 1987). In Lake Naivasha, water level fluctuations have shown dramatic impacts on fish and plant communities in species variations. Studies on Lake Victoria and Lake Chilwa by (Howard-williams & Gaudet, 1985) and by (Gaudet, 1979) on Lake Naivasha, showed that shallow lakes have risks of drying up because of rainfall patterns. These results are similar to the current study findings that demonstrated lake water levels strongly linked to the seasonal weather variations. The decrease can be associated to the reduction in phosphorous being released into the water

Our study findings on levels and variations of phosphorous at all the nine stations on the lake (0.20 mg/l - 0. 42 mg/l) are consistent with those (Kitaka et al., 2002; Ballot et al., 2009; Harper et al., 1990; Hubble & Harper, 2002) (0.5 mg/l to 1.2 mg/l; 0.07 mg/l - 0.02 mg/l 0.11 mg/l to 0.178 mg/l respectively.

From the study Chlorophyll-*a* values ranged from 0.32 mg/l to 0.42 mg/l in all stations. To the contrary studies by Kitaka et al. (2002) showed lower values of 0.031 mg/l while Ballot et al. (2009) values were higher 14.4 mg/l to 83.9 mg/l in comparison to our study. In 2009 the lake levels were very low and hence high light penetration leading to higher photosynthetic activity.

Considerable variations in water turbidity between our study and related ones on this lake were noted, the water shows signs of eutrophication (Richardson & Richardson, 2015; Stoof-Leichsenring et al., 2011). Our Secchi transparency values ranged from 32 cm to 84 cm which was comparable to (Harper et al., 1990) 164 cm to 40 cm in 1987 and Ballot et al. (2009) averaged 62 cm. Results showed that TSS in all stations recorded between 0.13 mg/l to 0.14 mg/l.

From the study in 2018, as the Lake levels increase, chlorophyll-*a* production increases. However in 2019, it is the opposite. Phosphorous displayed a common pattern or distribution in both months of 2018 and 2019.

Although nine sampling points represented the whole study area and twenty-four months of the study comparing the complexity of the lake can be a limitation, we record significant relationship between WLF and major ecosystem aspects. Phosphorous trends and other ecosystem aspects give insights of the importance of water level fluctuations as drivers of ecosystem structure and function of freshwater.

5. Recommendations

In recent years, Rift valley lakes have recorded increased lake levels, this is likely to cause economical and ecological risks. If the current situation of WLF continues; Lake Nakuru (1759 m.a.s.l.) is likely to connect with Lake Elementaita (1776 m.a.s.l.), while Lake Baringo (970 m.a.s.l.) is likely to connect with Lake Bogoria (990 m.a.s.l.), we recommend the government to put up tight measures to curb future loss of aquatic habitats and economies. More future studies both temporal and spatial on WLF and its relation to ecosystem aspects and other processes in tropical lakes are required both in Africa and other parts of the world.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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