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Diversity and Abundance of Some Microbial Communities in Kenya's Rift Valley Lakes Nakuru and Bogoria Before the 2019-2020 Long Rains

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Abstract The recent heavy rains in many parts of Kenya have changed several aspects of the Rift Valley lakes. Data collected before the rainfall events is therefore crucial for a better understanding of these systems hence the need for this paper. Two Rift Valley lakes in Kenya (Nakuru and Bogoria) were investigated between June 2008 and January 2009. The objective of the study was to investigate the dynamics and abundances of viruses, heterotrophic bacteria and phytoplankton biomass. Three sampling sites were selected in both Lakes. Temperature and conductivity were determined by probes in situ while Soluble Reactive Phosphorous (SRP) was determined using the ascorbic acid method. Dissolved Organic Carbon (DOC) was measured as non-purgeable organic carbon with a TOC-VCPH total organic carbon analyzer, while chl-a was extracted with acetone. Water samples for bacterio-virioplankton were fixed immediately after collection and enumeration of samples stained with SYBR Gold was done with epifluorescence microscopy. It was observed that conductivity was twice higher in Lake Bogoria than in Nakuru, and higher temperatures were recorded in the former than in the latter. DOC in Lake Nakuru was three times higher than that of Bogoria. Chl-a and SRP exhibited an antagonistic interrelationship. Virus abundances in Lake Nakuru ranged from 0.51-141.6 ×108 ml-1, among the highest observed in any natural aquatic system examined so far, and for Lake Bogoria the range was between 0.17-15.0 ×108 ml-1. The numbers of heterotrophic bacteria were one order of magnitude lower than that of viruses and virus to bacteria ratio (VBR) in both lakes. The study revealed that temperature and conductivity have effects on bacterial, viral numbers and phytoplankton, that cyanophages appear to play an important role in the dynamics of phytoplankton. Further, molecular and genetics studies could help to elucidate the interplay among microorganisms. Publishing this study now can provide valuable information for understanding the long-term dynamics of the microbial communities in these lakes and how they may be affected by changes in precipitation, which can inform conservation and management efforts in Kenya.

Keywords: *Bacterioplakton, viroplankton, saline lakes, lake Nakuru, lake Bogoria*

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1. Introduction

The soda lakes of the East African Rift System are unique water bodies whose formation, topography and locational settings have conferred upon them endorheic basin features with arid to semiarid climatic conditions. These features, together with the geological characteristics of their catchments, have favored the development of saline alkaline properties that make them peculiar and important from a number of perspectives. Most of these lakes have extreme environmental characteristics shown by high ionic contents of their water, high temperature conditions and eutrophic states. This enables them to support growth of few tolerant species of extremophilic Cyanobacteria and other microbes. Some of these lakes such as the Lakes Nakuru and Bogoria are highly productive, yielding some of the highest primary production rates in the world.

Even though it was conducted in 2008, this study on the bacterioplankton and virioplankton abundances and

dynamics in Kenya's saline Lakes Nakuru and Bogoria prior to the 2019-2020 long rains is still important to publish now because it establishes a baseline for the microbial community structure in these lakes. This information can be utilized to understand any changes or trends in the microbial populations through time by comparison with more recent information. For instance, it can be used to comprehend how, in the context of climate change, the microbial communities in these lakes react to variations in precipitation. This is especially important because Kenya's changing precipitation patterns would affect the biodiversity of these lakes, and the study might assist determine how climate change might affect these distinctive ecosystems. The study can also shed light on the microbial ecology of these saline lakes, which will help guide future research into how these particular ecosystems work and are managed. The research can also be utilized to advance scientific knowledge of these systems by enhancing our knowledge of the diversity, distribution, and responses to environmental changes of bacterioplankton and virioplankton in saline lakes.

Many studies have been done extensively on diseases of aquatic vascular plants, however there is little information on pathogenic interactions of bacteria and viruses [1], despite the fact that viruses and viral-like particles account for approximately 10% to 40% of bacterial mortality in marine and freshwater bacterioplankton [2]. These viral attacks can influence aquatic ecosystems including the Great Rift Valley endorheic saline-alkaline lakes whose microbial ecology has not yet been well studied and documented.

The Rift Valley lakes are low in biodiversity and thus ideal ecosystems for studies of biological aquatic dynamics and food webs [3,4]. These lakes have pH values above 10 and are amongst the most productive ecosystems in the world with primary productivity values up to 30 g O_2 m^{-2} d^{-1} [3,5,6]. They feature an enormous phytoplankton biomass dominated by the cyanobacterium *Arthrospira fusiformis* among others. Two alkaline Rift Valley Lakes Nakuru and Bogoria are among the world's famous flamingo lakes; whereby they have acquired international recognition as Ramsar sites and are now nationally protected as national parks and national game reserves respectively. They are vital to the Kenyan economy for their contribution to the tourism industry with the main attraction being the varied birdlife, mainly the hundreds of thousands of flamingos that inhabit them together with other wildlife. The lesser flamingos *Phoeniconaias minor* dominate with their numbers ranging between hundreds of thousands to a million birds [7] with *A. fusiformis* being their main food source [17]. A biomass greater than 0.06 g L^{-1} dry mass, equivalent to about 400 µg L^{-1} of Chl- *a* is required to sustain a flamingo population of approximately 800,000 birds as estimated for Lake Nakuru. Production models have indicated that the lakes pelagic primary productivity meets such a high demand when averaged over longer time periods [8]. Besides flamingos, the tilapine fish *Oreochromis grahami alcalicus* feeds directly on *A. fusiformis* in Nakuru. This fish in turn is predated upon by the pelicans (*Pelecanus onocrotalus*), which are found in high numbers in Lake Nakuru, forming another major attraction to the tourists. Thus, the importance of *A. fusiformis* for the stability of these ecosystems cannot be over-emphasized.

The main objective of this study therefore was to investigate the Bacterio- and virioplankton abundances and dynamics in a time series in these two saline lakes to better understand both the relationship and the correlations between these biotic aspects of the lake and the abiotic components. This paper brings to fore the situation within the lakes before the recent flooding occasioned by the high rains that could have changed the hydrological conditions of the lakes. The data in this paper will form a basis for the formulation of research ideas and hypotheses around the lakes.

2. Materials and Methods

2.1. Study Area

Two shallow saline-alkaline lakes within Kenya's Eastern arm of the Rift Valley were investigated, namely Nakuru and Bogoria (Figure 1). Lake Nakuru (0º 19'-24'S, 36º 04'- 07'E) is a shallow (maximum depth around 1.5 m) and a strongly alkaline endorheic lake covering about 3000-5000 ha [7], with greatly varying water level. The water source for the lake is mainly from precipitation and three seasonal low order rivers. Lake Bogoria (0º 15'N, 36º 06'E) on the other hand, is a narrow, shallow alkaline-saline lake that covers an area of about 3000 ha. It is fed by a few streams from the escarpment above it and some small impermanent tributaries that include the Emsoss and Wasagess rivers. It receives erratic and stormy rainfall that erodes the scarcely vegetated areas washing lots of sediment into the lake.

2.2. In-situ Measurements

Though most portable meters (used for pH, EC, and oxygen determination) are equipped with temperature sensors, Sensor (WTW oxy 340i) temperature values were read from the temperature sensor in the oxygen probe for specific depths. The electric conductivity of the lake water was measured using the Electrical conductivity probe (WTW 340i). The probe was dipped at specific depths and the EC readings taken. Before using, the probe was calibrated by using the standard 0.010 M KCl solution (conductivity 1430 µS/cm at 25°C).

2.3. Chemical Parameters

Soluble reactive phosphorus (SRP) was determined using the ascorbic acid method [9] on the filtered samples. All the glassware used for this analysis were soaked in 10% H_2SO_4 overnight and rinsed with distilled water. Dissolved organic carbon was measured as NPOC- non purgeable organic carbon - with a TOC-VCPH total organic carbon analyzer in combination with a total nitrogen measuring unit TMN-1.

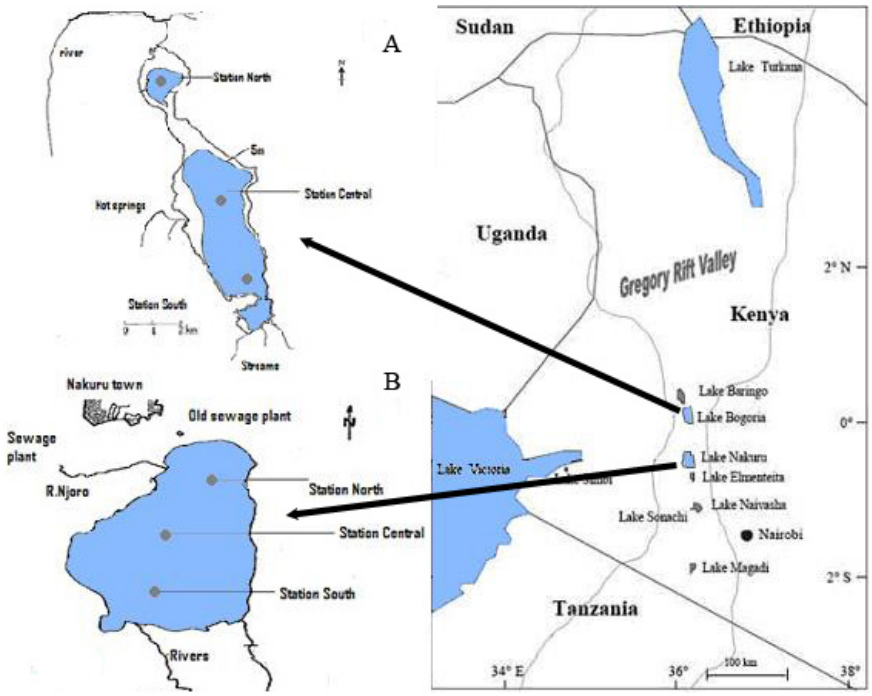

Figure 1. Map showing the geographic location of study areas (right). Insets are the specific different sampling locations for both A: Lake Bogoria B: Lake Nakuru

2.4. Sampling for Bacterioplankton and Virioplankton

Both lakes were sampled on a weekly basis. For each lake, three offshore sampling sites namely South, Central and North (Figure 1) were selected and their geographical positions determined by means of GPS. Sampling was done just below the surface and in addition, for Lake Bogoria, the central part was sampled at three different depths at 0, 3 and 5 meters. The water samples were taken by use of a dropper-tube, and in the depths, sampling was done by use of a Schindler sampler, then stored in plastic vials after fixation of heterotrophic bacteria and viruses (4% formaldehyde) then transported to the lab for further analysis.

2.5. Staining Procedure and Determination of Heterotrophic Bacteria and Virus Numbers

In the lab, protocols developed by Noble and Fuhrman, [2] were followed for sample staining. A 50 µl volume of formalin-fixed water sample was filtered, for Lake Nakuru the virus concentration was too high thus a 10 µl volume was filtered through Anodisc membrane (0.02 µm pore size) placed above a cellulose nitrate supporting filter and on a glass filtration device (vacuum pressure not exceeding 200 mbar). The Anodisc filter was dried, placed in a petri dish on a 50 µl drop of SYBR Gold [10] working solution with the side of the filter that retained the heterotrophic bacteria and viruses facing upwards, and kept in the dark for 30 minutes after which excess moisture from the staining solution was wicked away from the back side of the membrane with a soft tissue paper. The stained Anodisc filter was completely dried on the underside and mounted on a glass slide with a drop of anti-fade mounting reagent. The reagent used was Citifluor (Citifluor, London). A drop of Citifluor oil was placed onto a glass slide and the dry filter placed on it. Another drop of Citifluor oil was placed on top of the filter and then covered with a cover slip. The preparation was then stored frozen until counted via epifluorescence microscopy (Type: MOTIC, BA 400) and heterotrophic bacteria and viruses observed at 1000× magnification, under blue excitation (494nm) with a drop of immersion oil (Nikon) on the cover slip where the drop of oil was brought into contact with the objective and turned to focus until viruses and bacteria were observed. The working field was adjusted until approx. 20 viruses and bacteria were observed in the field, between 400-600 viruses and bacteria were counted in at least 30 randomly chosen fields. The following formula was used to come up with the final figures for further analysis and plotting.

$N=S\times10^{6}*n/s*v$

Where by:

S=filter area in mm^2; n=mean of viruses and bacteria per working field; v=volume of water filtered in ml; s=area of working field in μm^2; N=cells ml^{-1}.

2.6. Data Analysis

Data recorded was subjected to MS-Excel spread sheets and analyzed using the statistical program for social sciences SPSS 12.01; Normality of variables was tested using the Kolmogorov-Smirnov test, and Sigma Plot version 10 was used to plot the graphs. Kruskal Wallis test for independent samples was used to test significant differences among parameters and the Lakes. Regression analysis was used to show the relationship between parameters. Variables were correlated by means of the non-parametric Spearman rho correlation of significant relationships between the various parameters.

3. Results

3.1. Lake Nakuru

A summary of results for physico-chemical and biological parameters for Lake Nakuru during the sampling period are presented in Table 1.

Table 1. Summary of physico- chemical variables, bacterial and viral abundance in Lake Nakuru. SRP = Soluble reactive phosphorous, DOC = Dissolved organic carbon, HB = Heterotrophic bacteria (n = sample size, average values ± SD)

Variable	Range	Average	n
Conductivity [mS cm^{-1}]	25.2 – 33.8	29.2 ±1.8	86
Temperature [ºC]	21 – 28.9	24.9 ±1.9	86
SRP [µg L^{-1}]	0.00 - 701.5	180 ±146.7	86
DOC [mg L^{-1}]	144.6 – 278.2	214.1 ±22.2	71
Chl- *a* [µg L^{-1}]	46.4 – 685.2	252.2 ±123.3	85
Viral abundance [×10^8 cells ml^{-1}]	0.51 – 141.6	35.18 ±33.9	86
HB abundance [×10^7 cells ml^{-1}]	3.54 – 315.7	22.70 ±53.1	86

There were some variations in temperature in Lake Nakuru in the sampling stations as indicated by significant differences in temperature values between the three stations (n= 71, $p < 0.05$, Kruskal Wallis test). The temperature recorded ranged between 21- 28.9°C with a mean of 24.9 ± 1.9°C (Table 1). The distribution patterns for conductivity values at sampling sites in Lake Nakuru ranged between 25.2– 3.8 mS cm^{-1} with an average of 29.2 ± 1.8 mS cm^{-1} (Table 1). The conductivity measurements remained relatively similar within the sampling period with minor variations but in December, conductivity dropped sharply and suddenly due to suspected dilution from the stormy rainfall (Figure 2), and increased towards January when there was sunshine. However, there were no significant differences in conductivity between the three stations (n= 71, $p > 0.05$, Kruskal Wallis test).

The results for variation in SRP and chl-*a* and the average dynamics of the two recorded parameters in the sampling sites in Lake Nakuru during the sampling period are shown in Figures 3 a, b, c. SRP concentrations ranged between 0.00 - 701.5 7 µg L^{-1} and averaged at 180 ± 146.7 µg L^{-1}. SRP dropped when chl-*a* concentration increased but between September and October, SRP remained high while chl-*a* remained low (Figure 3c). At the beginning of sampling, chl-*a* concentration increased from July to September (Figure 3c), however thereafter a decrease coincided with a pronounced increase of viral abundance. Chl-*a* concentration recorded in Lake Nakuru was lowest with a value of 46.36 µg L^{-1} in Nakuru Central in December while the highest value was recorded at Nakuru North in August with a value of 685.52 µg L^{-1} (Figure 3a) and an average of 252.2 ± 123.3 µg L^{-1} (Table 1). There were no significant differences in SRP and chl-*a* concentrations between the three stations (n=71, $p > 0.05$, Kruskal Wallis test). Generally, there was a tendency for the two parameters to increase and decrease together. In October though, there was a decrease in chl-*a* despite availability of SRP (Figure 3c). This period coincides with high virus to bacteria ratio (VBR) and virus abundance suggesting the possibility of the viruses lysing the phytoplankton.

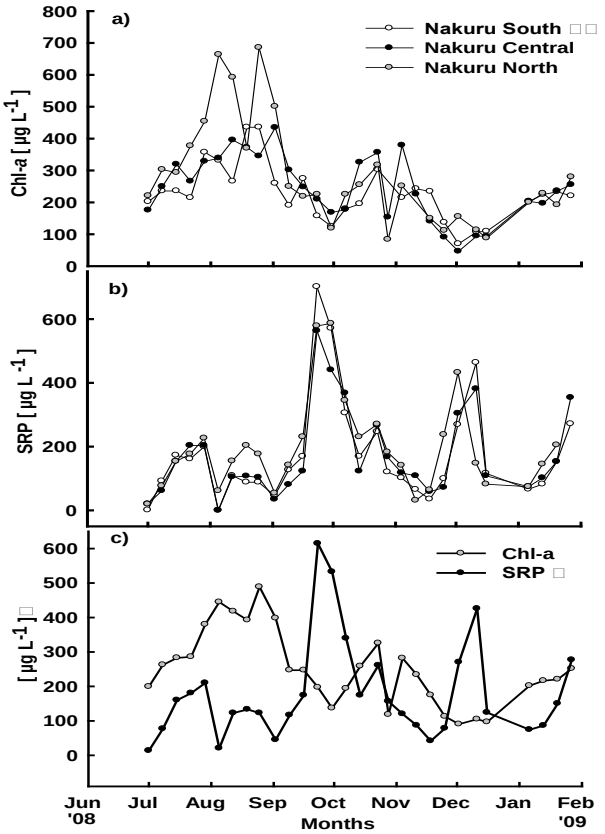

Figure 2. (a) Chl-*a*, (b) Soluble reactive phosphorous concentrations in samples collected from Lake Nakuru and (c) Average dynamics of SRP and chl-*a* during the sampling period

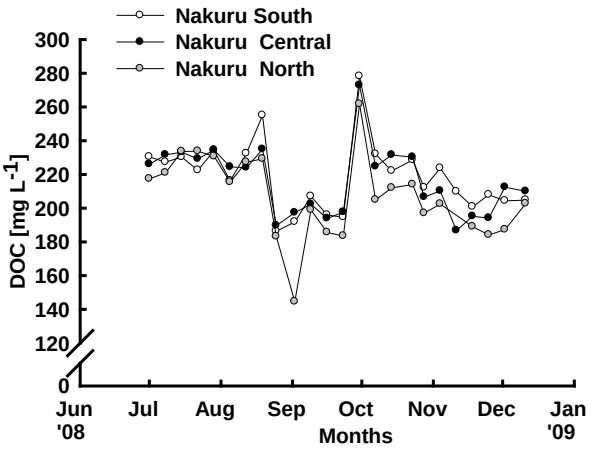

Figure 3. Dissolved organic carbon (DOC) concentrations recorded in samples from Lake Nakuru during the study period

The variation for DOC in sampling stations in Lake Nakuru are shown in Figure 4. DOC concentrations at the beginning tended to be relatively high followed by a period of sharp decline between September and October followed by a rise and thereafter a steady state prevailed for the rest of the period (Figure 4).

In Lake Nakuru, the number of viruses was generally one order of magnitude higher (10^8) compared to (10^7) what is found in most other aquatic systems. Viruses were low in numbers at the beginning of sampling with no major changes but as from September, viruses exhibited highly dynamic and drastic patterns throughout the sampling period at all the stations (Figure 5a). This study

combines all the viruses, whether from autotrophic or heterotrophic hosts. The lowest numbers of viruses were recorded at Nakuru North in July of 0.51× 10^8 ml^{-1} and the highest also at Nakuru North in December of 141.64× 10^8 ml^{-1} (Figure 5a). The average for the whole sampling period was 35.18 ×10^8 ml^{-1}± 33.87 for Lake Nakuru (Table 1). Heterotrophic bacteria showed variations during the sampling period except at the end of January when there was drastic increase in numbers (Figure 5b). The lowest abundance was recorded at Nakuru South in October at a value of 3.54 × 10^7 ml^{-1} while the highest was at Nakuru North of 315.72 × 10^7 ml^{-1} in January (Figure 5b). The average for the whole sampling period was 22.70 × 10^7 ml^{-1} ± 53.11 (Table 1).

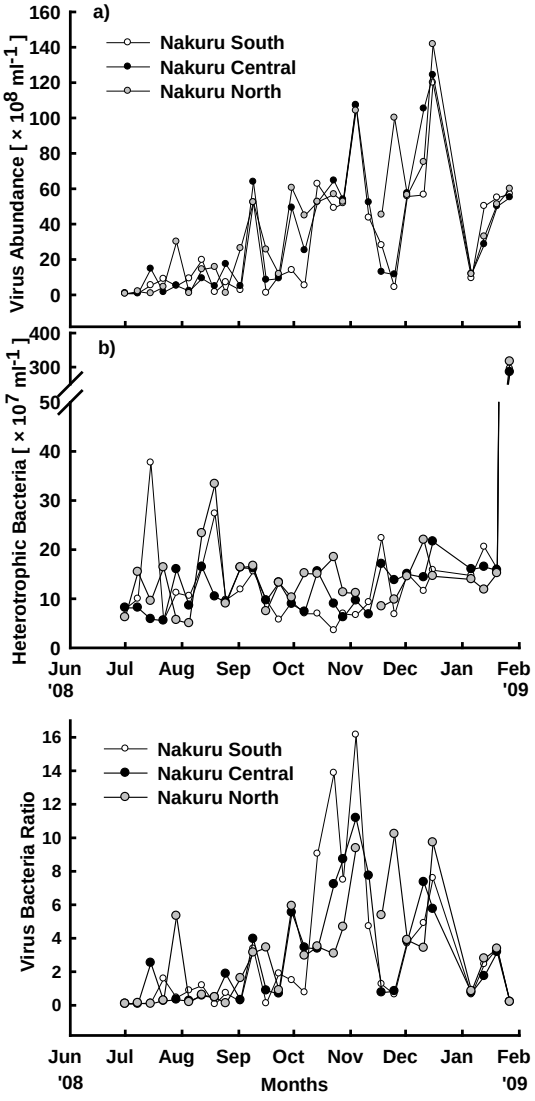

Figure 4. Bacterioplankton and viroplankton variations recorded in Lake Nakuru between June 2008 and February 2009 (a) = Viral abundance, (b) = Bacterial abundance and (c) = VBR at three sampling sites

Lowest virus to bacteria ratio (VBR) recorded was at Nakuru South (0.054) in August while the highest still was at Nakuru South of 16.14 in November (Figure 5c). The mean VBR was 3.00 ± 3.4 for the whole sampling period. VBR was high when the number of viruses was high and when bacterial numbers were relatively high. However, there were no significant differences in viral and bacterial numbers and VBR between the three stations (n=71, p > 0.05, Kruskal Wallis test) and a statistically interdependence between heterotrophic bacteria and viruses could not be found.

Some relationships between biological and limnological /limnochemical parameters for Lake Nakuru are presented in Table 2.

No interdependence was found between heterotrophic bacterial numbers and virus abundance indicating virioplankton are not necessarily all lytic bacteriophages. There was a significant negative influence of viral abundance on chl-a (Figure 6b; Table 2). This could probably be an indication that some of the virioplanktons are cyanophages. VBR also showed a negative correlation with bacterial numbers, but this was not significant (Figure 6c; Table 2). Of the abiotic parameters, SRP and temperature had a highly significant positive correlation with viral numbers but the interdependence with conductivity was negative (Table 2). There was no significant correlation between DOC concentrations and either bacteria or viruses indicating that probably some DOC could be from other environmental sources.

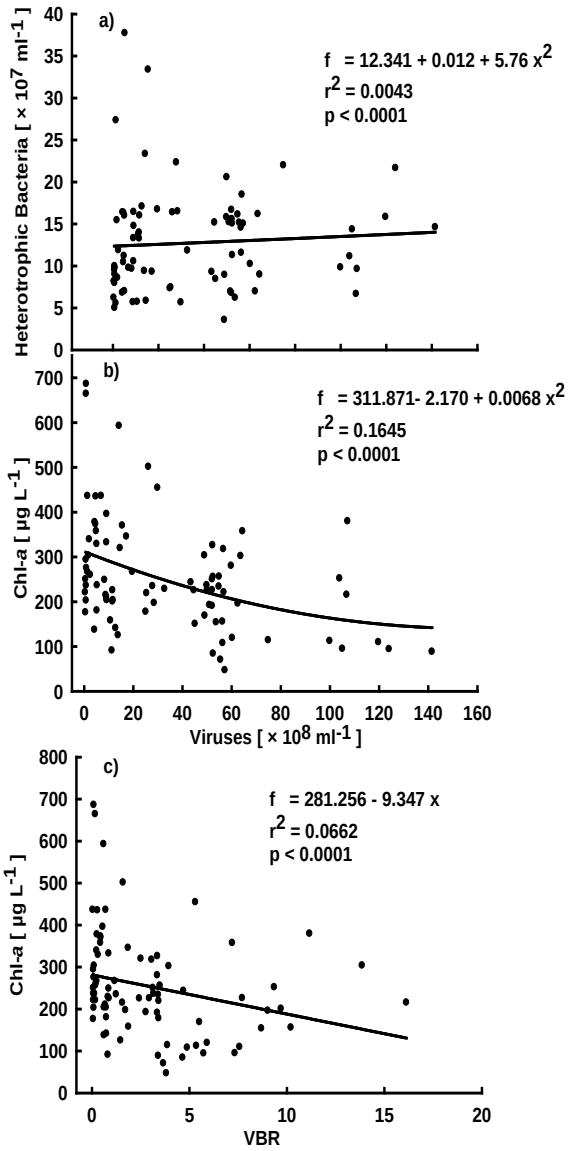

Figure 5. Regression relationships between chl-a and virioplankton or VBR and with heterotrophic bacterioplankton in Lake Nakuru

Table 2. Spearman rho correlation coefficients (r) for parameters in Lake Nakuru. HB = Heterotrophic bacteria, SRP = Soluble reactive phosphorous, DOC = Dissolved organic carbon

	Viruses	HB	VBR	Chl -a	n
HB	0.148		-0.170		71
Chl-a	-0.340**	0.121	-0.368**		70
SRP	0.374**	0.014	0.322**	0.260*	71
DOC	-0.222	-0.069	-0.219	0.192	71
Temp.	0.302*	0.013	0.264*	-0.258*	71
Cond.	-0.399**	-0.156	-0.371**	-0.361**	71

The various regression relationships of variables are presented in Figures 6a, b, c. All the relationships seemed to fit fairly with viruses and chl-a having the best fit as presented by the regression graphs below, whereby an increase in viral numbers and VBR resulted in a decrease in chl-a. The regression equations are shown at the right hand side of the curves.

3.2. Lake Bogoria

A summary of results for physico-chemical and biological parameters for Lake Bogoria are presented in Table 3 during the sampling period.

Chl-*a* concentration was high at the beginning of the first three months of sampling and somewhat reduced from September onwards (Figure 7a). SRP values recorded in Bogoria sampling sites are shown in Figure 7b. There was a tendency for SRP to remain moderately constant within the sampling period although fluctuations were observable for some sampling dates in each month. SRP fluctuated around 3000 µg L^{-1} and these values were nearly twenty times more than what was recorded for Lake Nakuru (Figure 7b). Generally, there was a tendency for the two variables to increase together except in a few cases where chl-*a* concentration remained low despite the availability of SRP (Figure 7c). There were insignificant differences in SRP between the different stations (n=71, $p > 0.05$, Kruskal Wallis test) but there were significant differences in chl-*a* concentration between the three stations (n = 71, $p < 0.05$, Kruskal Wallis test).

Table 3. Physico- chemical variables, bacterio - and virioplankton abundances in Lake Bogoria surface. SRP = soluble reactive phosphorous, DOC = dissolved organic carbon, HB = Heterotrophic bacteria (n = sample size, average values ± SD)

Variable	Range	Average	n
Conductivity [mS cm-1]	55.8 –69.9	60.9 ± 8.2	72
Temperature [oC]	25.5 – 33.4	28.4 ± 3.7	72
SRP [µg L-1]	1234 – 5895.2	2879.3 ± 870.7	73
DOC [mg L-1]	37.4 – 53.0	44.7 ± 3.7	70
Chl- a [µg L-1]	79.8 – 786.0	309.03 ± 129.7	70
Viral abundance [×108 cells ml-1]	0.17 – 15.0	5.1 ± 3.6	72
HB abundance [×107 cells ml-1]	1.19 – 17.3	6.8 ± 2.8	72

DOC values recorded in Bogoria sampling sites are shown in Figure 8. There was a trend for DOC to decrease downwards between July and August, increased in September but remained more or less constant in the rest of the sampling dates (Figure 8). DOC concentrations were not significantly different between the stations (n=70, $p > 0.05$, Kruskal Wallis test). DOC ranged between 37.4 – 53.0 mg L^{-1}, averaged at 44.7 ± 3.7 mg L^{-1} (Table 3) and these values were about five times lower than what was recorded for Lake Nakuru.

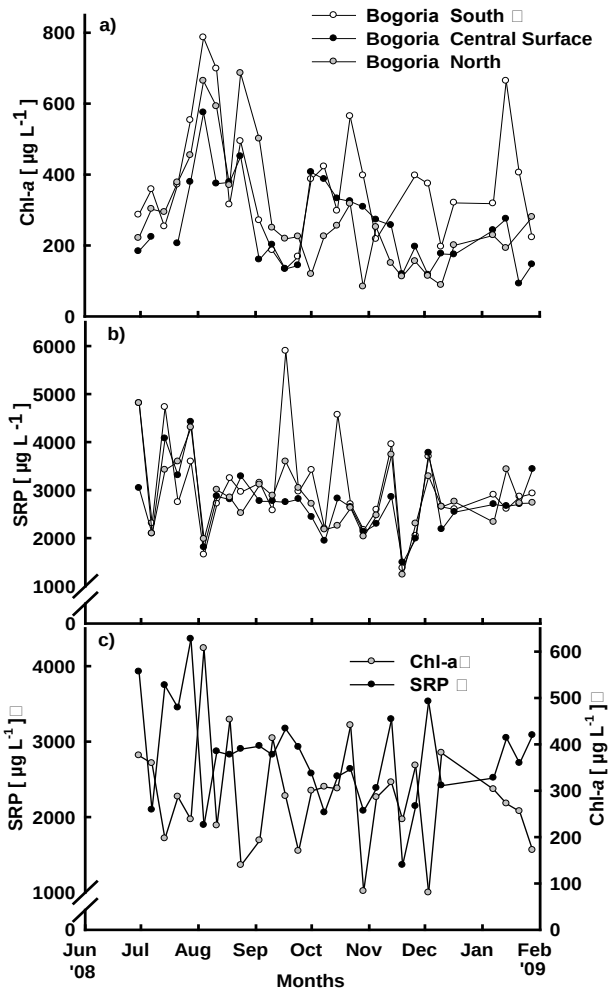

Figure 6. (a) Chl-*a*, (b) SRP concentrations and their average dynamics in Lake Bogoria surface

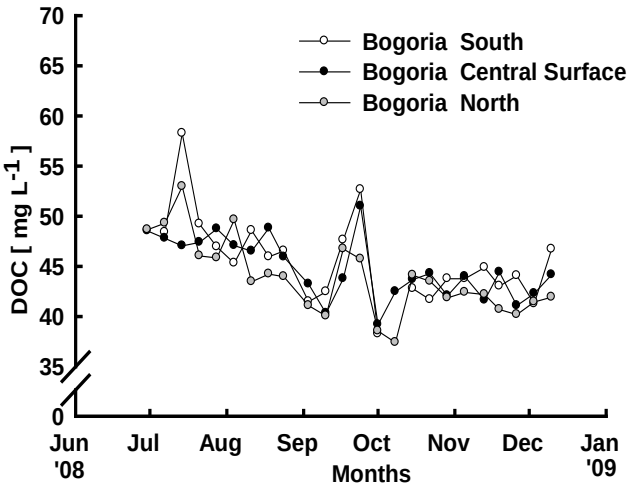

Figure 7. DOC concentration in Lake Bogoria surface water

The patterns for distribution of bacterio- and virioplankton abundances in the sampling sites in Lake Bogoria are indicated in Figure 9. The number of viruses and bacteria were one magnitude higher compared to other aquatic environments. The lowest number of viruses were

recorded at Bogoria central sampling site in surface water with 0.17 × 10^8 ml^{-1} in June 2008 and the highest, 15.00 × 10^8 ml^{-1} was at Bogoria North in July (Figure 9a). The average for the whole period was 5.05 × 10^8 ml^{-1} ± 3.6 (Table 3). Heterotrophic bacteria lowest and highest recorded were 1.19 × 10^7 ml^{-1} and 17.28 × 10^7 ml^{-1} respectively at Bogoria central (Figure 9b), with a mean of 6.8 × 10^7 ml^{-1} ± 2.8 for the whole sampling period (Table 3). During the whole sampling period, the bacteria and viruses exhibited highly dynamic patterns with large variability. Heterotrophic bacterial abundance ran mostly parallel with virus abundance (Figure 9a, b).

The virus to bacteria ratio (VBR) ranged between 0.02-2.26. The VBR value was high at Bogoria North (2.26) on July (Figure 9c) and at the same month heterotrophic bacterial numbers were relatively low (Figure 9b). The average VBR for the sampling sites was 0.86 ± 0.56. In overall, there were no significant differences in virus and bacterial numbers and VBR between the stations (n=72, p > 0.05, Kruskal Wallis test).

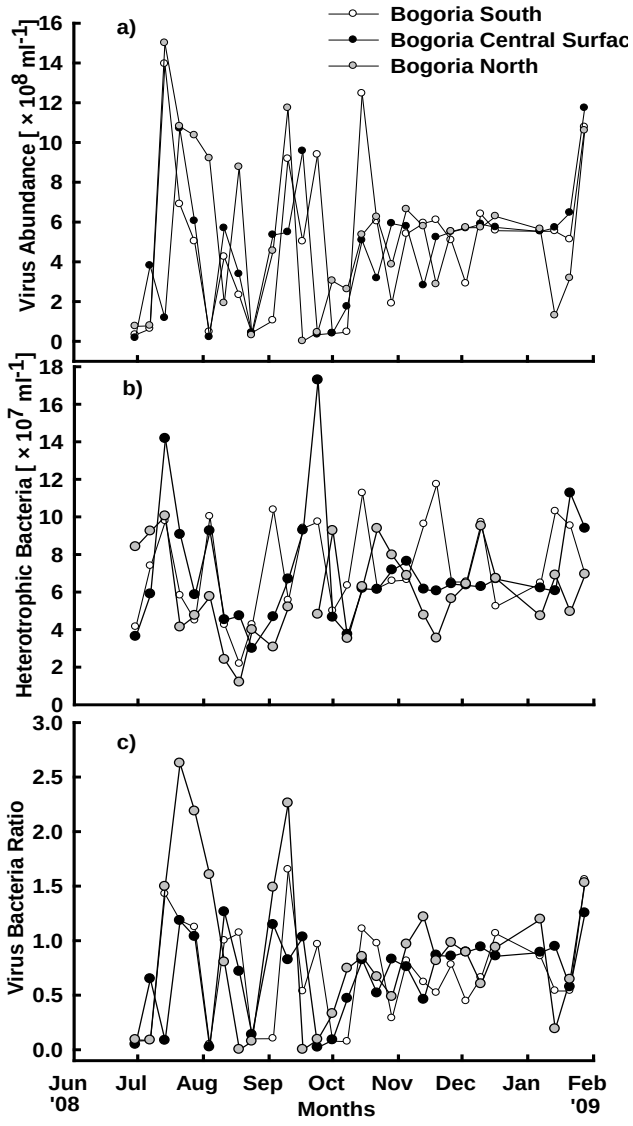

Figure 8. Bacterioplankton and virioplankton densities recorded in Lake Bogoria between June 2008 and February 2009 (a) =Viral abundance (b) =Bacterial abundance (c) =VBR at three sampling sites

The relationships between biotic and abiotic parameters for Lake Bogoria are presented in Table 4.

Several interdependencies between virus related variables, bacterial and environmental parameters were detected (Table 4). A positive significant interdependence was found between heterotrophic bacterial numbers and viral abundances. From the other abiotic parameters only conductivity showed a negative correlation with the viral numbers (Table 4) indicating a reduction of viral numbers with increased conductivity. Further, various relationships of variables are presented in Figure 10000a, b, c. All the relationships seemed to be fairly weak as presented by the regression curves.

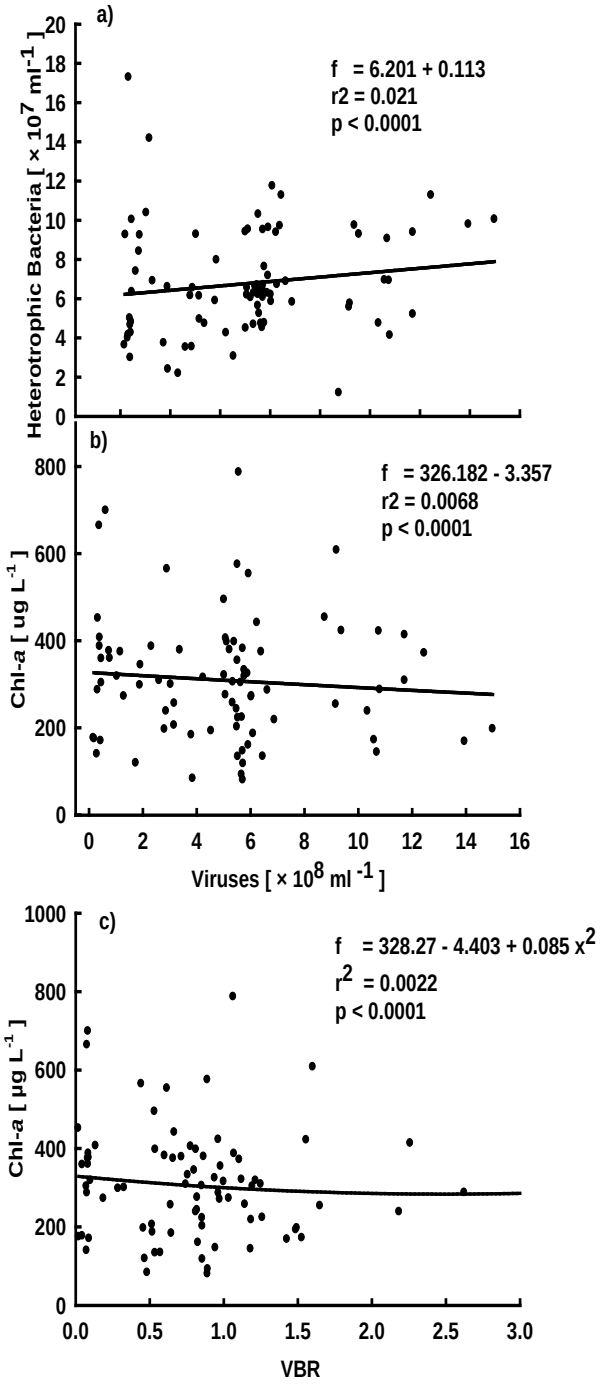

Figure 9. Regression relationships between virioplankton and chl-a or bacterioplankton and VBR with chl-a for Lake Bogoria

Table 4. Spearman correlation coefficients (r) for parameters in lake Bogoria (surface) HB = Heterotrophic bacteria, VBR =Virus to bacteria ratio

	Viruses	Bacteria	VBR	n
HB	0.266*		-0.213	72
VBR	0.835**	-0.213		72
Chl-a	-0.040	0.107	-0.103	71
DOC	0.043	0.152	0.013	69
SRP	0.130	-0.028	0.194	71
Temp.	-0.067	-0.100	-0.007	70
Cond.	-0.262*	-0.135	-0.126	69

4. Discussion

The discussion and interpretations offered in this part consider that the heavy rains and subsequent flooding of the two lakes have undoubtedly resulted in changes in the ecological characteristics of these systems, including those presented in this research. As previously stated, this study is required because the data obtained prior to these rainstorm occurrences could provide insights into what changes occurred as a result of the rains, and future or existing research ideas could be guided by this type of information.

4.1. Physico- chemical Parameters

The significant positive interdependence of viruses with temperature supports the high number of viruses in Lake Nakuru since water temperature is one controlling factor for the dynamics of aquatic environments [18]. Since Lake Nakuru is shallow, mixing lake, it is expected that the water should be uniform in temperature. The temperature ranged between 21 and 28.9°C (Table 1) which falls within the optimum for maximum growth of living organisms. This can explain the fact that in this study viral density in Lake Nakuru were about seven (7) times more than in Lake Bogoria while bacterial densities in Lake Nakuru were three (3) times more than in Lake Bogoria. On the other hand, the lack of significant correlation between temperature and viruses or heterotrophic bacteria could indicate that temperature does not have an effect on the growth of these microorganisms in Lake Bogoria but the correlation was a negative one meaning that increase in temperature leads to denaturing of these microbes. Talling and Lemoalle, [19] observed the same trend in temperature for the shallow lakes of East Africa, Lake George in Uganda and classified them as holomictic and warm polymictic lakes. Of particular interest is the strong but a negative interdependence with conductivity in both lakes which could indicate high levels of salinity do have a negative effect on viruses and to some extend bacterioplankton growth, the important hosts for virioplankton. This was opposite to what Guixa-Boixareu *et al*., [20] had found that, viruses are subject to destruction or decay when conductivity increases. This could suggest that conductivity would cause stress to the host cells inducing lysogenic virus cells to switch to lytic cycle.

The tendency for the two variables (SRP and chl-*a*) to increase together in both lakes, except in a few cases where chl-*a* concentration remained low despite the availability of SRP, could indicate that either the phytoplankton were not absorbing it or the phytoplankton had been lysed by viruses. The significant positive correlation of viruses with SRP for Lake Nakuru probably could indicate the requirement for phytoplankton growth which in return might serve as cyanophage hosts. The high SRP concentrations can possibly be explained by the lower algal biomass (chl-*a*) during the same period, while the minimum SRP concentrations corresponds to a peak of algal biomass [11]. Lake Bogoria SRP was seven times higher than in Nakuru as a result of the loads of sediment that is washed into the lake during stormy rainfall.

The DOC values in Lake Bogoria were in the higher range found in other saline lakes, for instance in Lakes Pendent 4.72 mg L^{-1}, Highway 8.21mg L^{-1}, and Williams 30.72 mg L^{-1}. On the other hand, Lake Nakuru DOC was 3 times higher that of Bogoria, probably due to high levels of activity, like cell lysis and decomposition of organic matter, since the lake neighbors an urban set-up with large farmlands and a rich biodiversity of wildlife and so the input of inorganic and organic matter can be high, probably this also explains the high numbers of bacteria found in this lake especially at Nakuru North, the point at which effluent from treated sewage gets into the lake. Maranger and Bird, [21] studied several lakes in Québec but did not find a significant correlation between viral abundance and DOC and so, it was for Lakes Nakuru and Bogoria. On the contrary, Laybourn-Parry *et al*., [22] found a positive relationship between DOC and viral abundance in the freshwater and saline lakes of Vestfold Hills, Antarctica.

4.2. Biological Parameters

Chl-*a* concentration for Lake Nakuru of 40 to 700 µg L^{-1} was comparable to that of Lake Bogoria of 70 to 800 µg L^{-1}. In both lakes, there was a significant negative influence of viral abundance on chl-*a*, and this might suggest that many of these viruses are phycoviruses or viruses infecting cyanobacteria hence the chl-*a* concentrations would have been even higher if it were not for the lysis though chl-*a* recorded by Melack, [3] of 330 and 350 µg L^{-1} for Lakes Nakuru and Bogoria respectively was low compared to the present. Viruses are very host specific and this conforms to our hypothesis that cyanophages may play a significant role in regulating phytoplankton biomass. Viruses that infect heterotrophic bacteria are different to those that attack phytoplankton [23] and this could be explained by the highly significant correlation between chl-*a* and viruses in Lake Nakuru which was not the case for Bogoria. Other studies carried out in Ethiopian soda lakes found out that chl-*a* was in the range of 1 to 600 µg L^{-1} [12].

Viral abundances were one order of magnitude higher than that of bacterioplankton. In this study, the range of viruses in Lakes Nakuru and Bogoria (surface) were found to be in the range of 0.51 - 141.64 × 10^8 ml^{-1} and 0.17 – 14 × 10^8 ml^{-1} respectively. The numbers are similar and even higher than the numbers obtained from Mono Lake of 0.1 to 1 × 10^9 ml^{-1} [13], therefore among the highest numbers reported for any natural aquatic environment. This study is the first one to come up with numbers of viruses in the Great Rift Valley lakes and the numbers seem to be extremely high compared to other studies done in other places. For example, viral numbers observed by Kirschner *et al*., [24] from ephemeral shallow saline pools in Austria

(up to 5×10^8 cells ml^{-1}), compares to a certain extent with the patterns found so far in the Rift Valley saline lakes. Virus abundance in Sri Lanka was one to two orders of magnitude lower compared to our estimated numbers and fluctuated between 2.0 and 7.7×10^7 viral particles ml^{-1} with the highest numbers recorded in the dry season. Our numbers are quite different from other estimates done by Johanna Laybourn-Parry *et al*., [22] where virus-like particles ranged from 1.01 to 3.28 $\times 10^6$ ml^{-1} in the freshwater lakes and between 6.76 and 36.5×10^6 ml^{-1} in saline lakes.

Bacterial abundances in the two alkaline saline lakes are in the range in literature [23]. Generally, the abundance of viruses in natural waters ranges from 10^4 ml^{-1} to above 10^9 ml^{-1}, while the number of bacteria varies between 10^4 to 10^7 ml^{-1}. However high bacterial numbers observed in Lake Nakuru (about three times more than in Lake Bogoria (surface) could probably be due to the fact that this lake is mixed throughout the water column and some of the bacterioplankton could be extracted from sediment whereas for Lake Bogoria it is never mixed probably accounting for the lower numbers. The range of bacterial numbers in Lakes Nakuru and Bogoria was found to be 3.54 to 315.72×10^7 ml^{-1} and 1.19- 17.3×10^7 ml^{-1} respectively and much more variable as compared to other studies, e.g. from Mono Lake in California in which the bacteria were in the range of 0.3 to 4.4×10^7 ml^{-1}. But at times similarly high numbers were reported for Lake Nakuru by Yasindi [14] of 2.0 $\times 10^9$ ml $^{-1}$. Our numbers are two orders of magnitude higher when compared to a study on bacterial abundance in Sri Lankan tropical waters by Peduzzi and Schiemer, [15], where they found out that bacterial abundance ranged between 20.9 and 47.3×10^5 cells ml^{-1}. Expectedly, a fair interdependency existed between virus distribution and host bacterioplankton.

High VBR means more viruses than bacteria but gives also some information on virus replication. The VBRs found in this study are low, medium to high (i.e. very variable) compared with values reviewed by Wommack and Colwell, [23]. For Lake Nakuru, the values ranged from 0.05 to 16.14 which were seemingly high compared to VBR of Lake Bogoria (surface) of 0.02 to 2.26 and are within the reported VBR range. Generally, the ratio of virus to bacterial abundance falls between 3 and 10 [23] VBR values were comparable to others observed in Sri Lankan tropical reservoirs where the calculated virus to bacterium ratio (VBR) ranged between 9.7 and 23.8 [15]. Field studies of Tampa Bay [16], Arctic sea ice [25], Canadian lakes [21], and seawater mesocosms [26] have all provided results showing that the VBR decreases as bacterial abundance increases. Despite the fact that various relationships (from positive to inverse) between VBR and bacterial abundance have been reported in the literature, negative correlations are typical [23] This applies to our study since no significant correlation was observed between VBR and bacterial abundance in both lakes. Furthermore, both lakes showed no significant differences in bacteria, viruses, DOC, VBR ($p > 0.05$) and this could indicate that the lakes are of similar properties.

Conclusion and Recommendation

The purpose of this study was to investigate at the diversity and abundance of microbial communities in two Rift Valley lakes in Kenya, Nakuru and Bogoria, before the long rains that occurred in the later parts of 2010s and early 2020s. The examination of temperature, conductivity, dissolved organic carbon, and phytoplankton biomass revealed considerable disparities in the two lakes' properties. Lake Bogoria, for example, had higher conductivity and temperatures, whereas Lake Nakuru had higher dissolved organic carbon. Furthermore, the study discovered a significant abundance of viruses in both lakes, with comparatively high viral to bacteria ratios. The study also revealed that temperature and conductivity have an effect on bacterial, viral, and phytoplankton levels, and that cyanophages appear to play an essential role in phytoplankton dynamics. This study suggests that further research using molecular and genetic techniques may provide more insight into the interplay among microorganisms in these lakes

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