Assessing the impacts of climate variability and climate change on biodiversity in Lake Nakuru, Kenya

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Abstract. Wambui MB, Opere A, Githaiga MJ, Karanja FK. 2017. Assessing the impacts of climate variability and climate change on biodiversity in Lake Nakuru, Kenya. Bonorowo Wetlands 1: 13-24. This study evaluates the impacts of the raised water levels and the flooding of Lake Nakuru and its surrounding areas on biodiversity, specifically, the phytoplankton and lesser flamingo communities, due to climate change and climate variability. The study was to review and analyze noticed climatic records from 2000 to 2014. Several methods were used to ascertain the past and current trends of climatic parameters (temperature, rainfall and evaporation), and also the physicochemical characteristics of Lake Nakuru (conductivity, phytoplankton, lesser flamingos and the lake depth). These included time series analysis, and trend analysis, so the Pearson’s correlation analysis was used to show a relationship between the alterations in lake conductivity to alterations in population estimates of the lesser flamingos and the phytoplankton. Data set extracted from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (IPCC Fifth Assessment Report (AR5) Atlas subset) models were subjected to time series analysis method where the future climate scenarios of near surface temperature, rainfall and evaporation were plotted for the period 2017 to 2100 (projection) for RCP2.6 and RCP8.5 relative to the baseline period 1971 to 2000 in Lake Nakuru were analysed. The results were used to evaluate the impact of climate change on the lesser flamingos and phytoplankton abundance. It was noticed that there was a raise in the mean annual rainfall during the study period (2009 to 2014) which brought the increment in the lake’s surface area from a low area of 31.8 km² in January 2010 to a high of 54.7 km² in Sept 2013, indicating an increment of 22.9 km² (71.92% surface area increment). Mean conductivity of the lake also lessened leading to the loss of phytoplankton on which flamingos feed making them to migrate. A strong positive correlation between conductivity and the lesser flamingo population was noticed signifying that low conductivity affects the growth of phytoplankton and since the lesser flamingos depend on the phytoplankton for their feed, this subsequently revealed that the phytoplankton density could be a notable predictor of the lesser flamingo occurrence in Lake Nakuru. There was also a strong positive correlation noticed between phytoplankton and the lesser flamingo population which confirms that feed availability is a key determining factor of the lesser flamingo distribution in the lake. It is projected that there would be an increment in temperatures, rainfall and evaporation for the period 2017 to 2100 under RCP2.6 and RCP8.5 relative to the baseline period 1971 to 2000 obtained from the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model ensemble. As a result, it is expected that the lake will further increment in surface area and depth by the year 2100 due to increased rainfall thereby affecting the populations of the lesser flamingos and phytoplankton, as the physicochemical factors of the lake will alter as well during the projected period.

Keywords: Biodiversity, climate change, Lake Nakuru, Kenya

INTRODUCTION

Africa has been known as one of the most easily damaged regions in the world regarding climate change, according to the Fourth Assessment report from the Intergovernmental Panel on Climate Change (IPCC 2007). A report stated that there are some areas in Africa which evidently are highly vulnerable to climate variability and change. Increased changes and variability of different climatic factors have been forecasted by Kenya’s current climate predictions. Severe challenges to sustainable development are being propounded by climate change in Kenya, as it’s possibly a major environmental challenge of our time (Mutai et al. 2010). Focusing on effects of climate change on water resources, coastal zones, ecosystems, health, industrial activity, food and human settlements, propounds chances for improved livelihoods, business and innovation.

Various patterns of rainfall and rising temperatures have also worsened the problem of wetlands drying out, thereby threatening water availability leading to lessened agricultural production and thus accruing food insecurity due to lessening yields in crop. Various patterns of rainfall have posed threats to the renowned wildlife safaris in Kenya, and especially to one of the Seven Wonders of the World: The Mara River migration of wildebeests, which is common with tourists around the world (Climate Action Network 2009). Intermittent patterns of rain affect the wildebeests as their migration is influenced by the smell of rain, since the pattern of migration is usually timed to show a relationship between the growth of grass and annual rainfall patterns in the North. Drawing closer to March, which is characterized by a season of short dryness, the wildebeests begin migrating from Serengeti as the grass starts drying out towards the western Serengeti woodlands. By end of June when the long rains commence to decline in
Kenya, the wildbeest from the Western Serengeti is noticed in the Maasai Mara Game Reserve. Scarcely vegetation and the drying-up of rivers, owing to unpredictable climate, has caused huge losses in wildlife numbers (Climate Action Network 2009).

There is an extensive variety of wildlife and ecosystems in Kenya, populating in air, water and land. Biodiversity assets known in Kenya include 7,000 plant species, 315 mammals, 1,133 birds, 25,000 invertebrates (21,575 of which are insects), 191 reptiles, 692 marine and brackish fish, 180 freshwater fish, 88 amphibians and about 2,000 species of fungi and bacteria (NEMA 2009a). Kenya boasts a large population of mammalian species’ ranking it third in Africa, with fourteen of these species endemic to the country (IGAD 2007). Large mammals such as the African elephant (Loxodonta africana), leopard (Panthera pardus), black rhino (Diceros bicornis), African lion (Panthera leo) and buffalo (Syncerus cafer) have made the country become popular due to their diverse nature (NEMA 2009a). According to the IUCN Threat Criteria (2008), 146 plant species of the 7000 found in Kenya have been assessed with 103 being classified as threatened (vulnerable, endangered or seriously endangered) (NEMA 2011).

In Kenya, threats to biodiversity have been on the increment over the past decades due to human-wildlife conflicts, habitat loss, population increment and infrastructure development, global climate change, pollution, biopiracy, poaching and overexploitation, invasive alien species and biosafety concerns (Government of Kenya (GoK), National Environment Management Agency (NEMA 2011). In this regard, safeguarding these biodiversity will be critical to securing livelihoods resulting to reduced levels of poverty - reflecting a population of 46.6 percent - suggesting a nine percent alteration if the social equity scales are to be attained as projected by the Vision 2030’s social pillar (NEMA 2011).

Provided crucial coping, mitigation and adaptation approaches are realized, future climate variability and climate change impacts can be avoided, delayed or reduced. About US $500 million per year was needed in Kenya to address the climate change effects by 2012 (Stockholm Environment Institute 2009). US $1-2 billion per year was the amount this figure was forecasted to raise by 2030 (Stockholm Environment Institute 2009). The collective effect of impacts of climate change will limit the realization of Vision 2030 targets, unless there is an urgent institutionalization of effective adaptation and mitigation mechanisms. As such, in order to tackle climate change, a range of policy instruments need to be formulated. A national policy on climate change need to be formulated and a climate change law further enacted, recognizing that the National Climate Change Response Strategy (NCCRS) was finalized in 2010. The country will not only be economically affected by the impacts of climate change but also its biodiversity heritage.

The main objective of the research was to evaluate the impacts of climate variability and climate change on Lake Nakuru’s biodiversity, Kenya, i.e., (i) to estimate the trends of past and present climatic records, and especially the temperature, rainfall and evaporation, of Lake Nakuru basin in order to understand the causes of increased lake levels. (ii) to show a relationship between alterations in lake conductivity to alterations in population estimates of aquatic species especially the phytoplankton and the lesser flamingos of Lake Nakuru basin. (iii) Evaluate in light of future climate projections, especially temperature, rainfall, and evaporation, the likely impacts of climate change on Kenya’s biodiversity especially the lesser flamingos and phytoplankton in Lake Nakuru basin.

MATERIALS AND METHODS

Area of study
The study site was Lake Nakuru. It was chosen because it is one of the most important habitats for the flamingo species and also one of the important tourist destinations in Kenya. Lake Nakuru National Park, Kenya is located between 0°19'- 0°24' S and 36°04'-36°07 E, approximately 3km South of Nakuru town, Kenya. It lies in a graben between Lion Hill fracture zone in the east and a series of east downthrown step-fault scarps leading to the Mau Escarpment to the west.

Lake Nakuru extends in the N-S direction in the trend of the axial rift faults as shown by Figure 1. It includes other chains of alkaline-saline lakes in the eastern arm of the Rift Valley, Kenya. Existing more than twelve million years, one of the earth’s spectacular geological formations was formed by the catchment and its landforms which included rifts, cliffs, mountains, volcanoes and lakes (Odada et al. 2006). Progressions of characteristics and features that describe Lake Nakuru have been influenced by climate, evolutionary history and Geography. Levels of productivity and successful establishment of species have been ascertained by these features which set in motion the chemistry of the lakes’ water. The ecosystem of the lake is made unique by the chemistry of the alkaline water which depends on the larger catchment for sustenance and independent of its immediate environment for it functions. White salt files swirling with dust devils are sometimes created when there are enormous water body reductions resulting from alterations in the surface area of the lake.

Data type
Data used in this study included climatic data comprising of mean annual temperature, mean annual rainfall mean annual evaporation and the Coupled Model Intercomparison Project Phase 5 (CMIP5) Representative Concentration Pathways (RCP2.6 and RCP8.5) near surface temperature, rainfall and evaporation data. Lake data comprised of conductivity, lake levels, surface area and depth. Flamingo data comprised of the lesser flamingo population. Below is a detailed description of the data types and their sources.

Procedures
In this section, the methods that were used in the study for data collection, organization and analysis based on the specific objectives of the study are propounded.
**Study design and sample size determination**

Sample and sample size identification was purposive and quantitative. Four sites Nderit, Makalia, Baboon Cliff and Lion Hill, were selected as sampling sites/stations for the collection of water samples which were used to ascertain the levels of phytoplankton population densities, species composition and conductivity measurements in the lake in 2014. The sampling sites were largely ascertained by their accessibility as the lake was quite flooded at the time leading to the loss/damage of the road infrastructure which limited access to other sites. Water samples from the lake were collected in four replicates, fortnightly, in August 2014 and the first half of September 2014. The study sought to investigate the impact of climate variability and climate change on Lake Nakuru’s biodiversity on the following indicators: (i) Lake levels (surface area and depth), (ii) Conductivity levels, (iii) Alteration in species populations of the phytoplankton and the lesser flamingos.

**Data sources**

Field visits and preliminary assessments. The water samples collected were used to ascertain the levels of phytoplankton population densities, species composition and conductivity measurements in the lake in 2014. These measurements were compared with data acquired from the Kenya Wildlife Service database for the period 2009 to 2014. Samples were collected in sterile bottles and transported in a cool box to the laboratory at the School of Biological Sciences, Chiromo Campus, University of Nairobi, where ex situ measurements of conductivity and phytoplankton concentration were conducted. Before analysis, the samples were stored in a fridge in the laboratory.

A Hanna Multi-parameter Water Analyzer Model HI 9828 was used to measure the conductivity of the water samples collected. The mean value of the four replicates was ascertained for each sampling site which was used to compute the mean conductivity of the lake. To ascertain the phytoplankton cells concentration and species identification one replicate from each site was randomly selected. 1 µL was taken from the bottle and suspended and centrifuged in 100 µL sterilized water. 1 µL of this suspension was placed on a glass slide and noticed under a LEICA DM500 microscope where the number of individuals in the field of view (quadrant) were counted and identified. This process was replicated for the other samples.

**Populations of lesser flamingos.** Data on population estimates of the lesser flamingos in the lake for the period 2009 to 2014 was collected from the KWS Bi-annual Waterfowl Count Report- Kenya Rift Valley Lakes ascertained using a modification of a method as described by (Pomeroy & Dranzoa, 1997). The information was used to ascertain the recent population trends and movement patterns of lesser flamingo in the context of flooding and the extensive dilution of the lake and show a relationship.
between the alterations in lake conductivity to alterations in the population estimates of the phytoplankton and lesser flamingo for the period 2009 to 2014. The data was based on records of the January water bird counts that are conducted jointly by the National Museums of Kenya and Kenya Wildlife Service.

Alterations in the lake levels. Data to ascertain the alterations in the lake surface area and depth was obtained from (Onywere et al. 2013) and the Kenya Wildlife Service records respectively. Documentation of the alterations in the lake surface area was made using Geographic Information System (GIS) digital techniques and information extraction and representation from Landsat satellite image data for January 2010, May 2013 and September 2013 and October 2013 (Onywere et al. 2013), whereas monthly measurements of the depth of the lake was collected from KWS. This had been ascertained from the readings of a staff gauge located at the lake centre.

Physicochemical characteristics of water (phytoplankton concentration and conductivity). The physicochemical qualities of water (phytoplankton concentration and conductivity) for the period 2009-2013 were obtained from the Kenya Wildlife Service (KWS) database. Monthly measurements of conductivity and concentration of phytoplankton in lake water had been ascertained based on monthly analysis of water taken from the lake centre. Conductivity had been ascertained using a pH meter. The concentration of phytoplankton had been ascertained using the Sedgewick-Rafter counting chamber as described by Kimberly (1999).

Noticed climate data. The climatic data (Rainfall, temperature, evaporation) for the period 2009 to 2014 was collected from the Kenya Meteorological Department, based on monthly data from the Nakuru Meteorological Station - 9036261(0.28°S, 36.1°E), located 3km north of the lake at the Nakuru Agricultural show grounds.

Climate projection data sets. In this study, the projected alterations in near surface temperature, rainfall and evaporation for Lake Nakuru were extracted from the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble (IPCC Fifth Assessment Report (AR5) Atlas subset) models. The output data were extracted as a relative alteration from 1971 to 2000 (baseline) to, 2017 to 2100 (projection) under two scenarios, namely, the RCP2.6 and RCP8.5 scenarios (Taylor et al. 2012). The RCP2.6 and RCP8.5 represent ‘low’ (RCP2.6) and ‘high’ (RCP8.5) scenarios featured by the radiative forcings of 2.6 and 8.5 Wm−2 by 2100, respectively. The CO2 equivalent concentrations in the radiative forcings of 2.6 and 8.5 Wm−2 by 2100, with respect to the situation before industrialization. RCP2.6 and RCP8.5 were chosen for this study as they

Data quality control

Data quality control was conducted to ensure that the data sets were devoid of missing values, consistent, uniformly entered and arranged to facilitate further processing. The data was then subjected to various statistical computations.

Homogeneity test. Most long-term climatological data records have been affected by a number of non-climatic factors that make these records unsuitable for comparison over long time periods and between different stations. These relate to alterations that can affect instruments, site, or procedures and methods in the observations and data processing. These factors are caused by alterations in: instrumentation, observation practices, location of station, and formulae used for means calculation, and changing the environment of the station. While some alterations make critical discontinuities, others, particularly alterations around station environment, due for example to, urbanisation, causes data biases which are gradual leading to time series biases and studied climate misinterpretations. In this study, the cumulative mass curve technique described in the subsection below was used to test for data homogeneity.

Mass curve. Mass curve analysis entails plotting of cumulative climatological data records against time to depict the homogeneity. The patterns of these graphs can be used to test for the quality of the records. A single straight line indicates a homogeneous record whereas heterogeneity tendency is indicated by existence of more than one line fitted to the graphical plots of the cumulative data. For the heterogeneous records, correcting the heterogeneity would be the next step. Double mass curves are commonly used to adjust heterogeneous records whose principles are similar to those of mass curves. In this study, the single mass curve technique was used to test the data homogeneity. A straight line graph depicted homogeneous data.

Time series analysis

Time series is the organization of statistical data in chronological order; in order with its time of occurrence. In this study a plotting of the annual means of rainfall, temperature and evaporation data for the period 2000 to 2014 using graphical method was undertaken. In addition, annual data means for lake depth, lesser flamingo population, conductivity, and phytoplankton levels for the period 2009 to 2014 were also plotted.

In order to ascertain the projected alterations in near surface temperature, rainfall and evaporation for Lake Nakuru, data extracted from the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model
ensemble (IPCC Fifth Assessment Report (AR5) Atlas subset) models were plotted using the KNMI (2015) to analyse the data for the period 2017 to 2100 for RCP2.6 and RCP8.5 relative to the baseline period 1971-2000.

The trend is characterized by the long term movement that is either represented by a growth or decline in a time series through a lengthy period of time. The trend in time series in this study, graphical method was used to ascertain the past and current trends of climatic parameters (temperature, rainfall and evaporation), and also for the physicochemical characteristics of Lake Nakuru (conductivity, phytoplankton, lesser flamingos and the lake depth).

Standard error of the mean was used to provide information about the distribution of the values within the trends as shown by Equation (1).

\[
\sigma_M = \frac{\sigma}{\sqrt{N}}
\]

Where, \(\sigma_M\) is the standard error of the mean, \(\sigma\) is the standard deviation of the original distribution and \(N\) is the sample size (the number of counts each mean is based upon). Specifically in this study, the error bars were fitted graphically to evaluate whether there was a notable difference between the data sets. While a larger sample size suggests a smaller standard error of the mean, overlapping error bars implies that the difference is usually not notable. However, when the error bars do not overlap, it suggests that the difference is notable.

Correlation analysis

The Pearson Correlation coefficient (r), given in equation (2), was used to quantify the degree of relations between pairs of study variables. It is used extensively as a measure of the degree of linear dependence among two variables. If two variables ‘x’ and ‘y’ are so related, where, ‘x’ is the conductivity of the lake and where, ‘y’ is represented by either the phytoplankton or the lesser flamingos, the variables in the magnitude of one variable tend to be accompanied by variations in the magnitude of the other variable, they are said to be associated. Therefore, correlation as a statistical tool helps to ascertain whether or not two or more variables associate and if they are associated, the degree and direction of their correlation.

\[
r = \frac{n \left( \sum xy \right) - \left( \sum x \right) \left( \sum y \right)}{\sqrt{\left( n \sum x^2 \right) - \left( \sum x \right)^2} \sqrt{\left( n \sum y^2 \right) - \left( \sum y \right)^2}}
\]

Where, \(r\) is the Pearson correlation coefficient, \(N\) is the sample size, \(\sum xy\) is the sum of the products of paired scores, \(\sum x\) is the sum of x scores, \(\sum y\) is the sum of y scores, and \(\sum x^2\) is the sum of squared x scores.

The student T-test was used to test for the significance of the correlation coefficient. The computed t-statistic derived from Equation (3), was compared with the tabulated t-value of the student t-distribution at the \(n-2\) degrees of freedom and 5% significance level.

\[
t_{n-2} = r \sqrt{\frac{(n-2)}{1-r^2}}
\]

Where, \(n\) represents the length of the data that were used, \(n-2\) is the degree of the freedom, \(n-2\) is the computed t-statistic and \(r\) is the Pearson correlation coefficient.

Correlation coefficient was deemed to be notable if the computed value of \(t\) was greater than the tabulated value at the 5% significance level. This is usually conducted to ascertain whether the linear relationship in the sample data is strong enough to use to model the relationship in the population.

RESULTS AND DISCUSSION

Data quality control

In this section, results of data quality control are propounded and their suitability for the study established. Specifically this section propounds results of the homogeneity test. The Figures 2 and 3 show simple mass curves for rainfall and temperature respectively. It can be noticed from Figures 2 and 3 that the rainfall and temperature data sets were homogeneous, owing to the resistant straight line plots. It can be noted that generally the rainfall has been gradually accruing leading to an increment in the surface runoff, most of which subsequently ended up in the lake.

![Figure 2. Single mass curve, cumulative annual rainfall](image)

![Figure 3. Single mass curve, cumulative annual temperature](image)
Past and present climatic record of Lake Nakuru from 2000 to 2014

Trend analysis of climatic data

Trends in rainfall patterns from 2000 to 2014. There has been marked variability of the mean annual rainfall patterns of Lake Nakuru basin with major rainfall intensification in the years 2000 to 2001 and 2009 to 2010, with the highest (120 mm) being recorded in 2010 (Figure 4).

Trends in temperature patterns from 2000 to 2014. Mean annual temperatures has been on a lessening trend during the period 2000 to 2014, with the highest temperatures being recorded in 2000 (26.6°C) and in 2009 (27°C) (Figure 5). Evaporation in the Lake Nakuru basin shows a declining trend over the study period (Figure 6). However, the noticed decrement in evaporation from the year 2009 is consistent with the increment in rainfall noticed in Figure 4 and temperature decrement noticed in Figure 5.

Alterations in the lake levels (depth and surface area) 2009 to 2014. Time series of Lake Nakuru levels (depth). Lake Nakuru levels have been rising over the years 2009 to 2014 (Figure 7). As seen in Figure 7, the mean depth of the lake rapidly increased during the study period (2009 to 2014). This could have been caused by increased rainfall during the study period which led to increased surface runoff and direct rainfall into the lake. The increased water levels led to the flooding of the lake which further lowered the conductivity of the lake as more fresh water was added into it.

Alterations in the lake surface area

Lake Nakuru’s surface area increased from an area of 31.8 km² in January 2010 to a high of 54.7 km² in Sept 2013 (Figure 8 and 9), an increment of 22.9 km² (71.9%). This led to the submergence of 60% of the transport infrastructure in Lake Nakuru Nationa Park and the park’s main gate, during this period, thereby displacing wildlife. At the highest level, the lake expanded and submerged areas that have never been recorded in the last 100 years (Figure 9). The extent of the flooded area and the impacts are illustrated in the image data and digitized maps shown in Figure 10.

Conductivity, phytoplankton levels and the lesser flamingos populations

Conductivity levels

The mean conductivity of Lake Nakuru lessened from the period 2009 to 2014 (Figure 11).
This coincided with the beginning of the rains from the year 2010 as shown in Figure 4. The declining conductivity of the lake could result into loss of phytoplankton (reduction in food supply) upon which the lesser flamingos feed. This could eventually lead to the migration of the lesser flamingos from the lake. This is due to the fact that as more fresh water was added to the lake, it lowered the conductivity of the lake because fresh water has low conductivity and the increment in water levels dilutes mineral concentrations.

**Phytoplankton levels**

The phytoplankton levels in Lake Nakuru were quite variable for the years 2009 to 2014 as shown by Figure 12. Notably, however, there was a general reduction in the phytoplankton levels which coincided with the onset of the rains from the year 2010 as shown in Figure 4. Phytoplankton levels lessened from 606 Units/mL in 2010 to 187 Units/mL in 2012. However, there was an increment in the phytoplankton levels to 321 Units/mL in 2013 which could have been caused by alterations in phytoplankton species composition and diversity that in turn affected their abundance due to alterations in the chemical and physical properties of the water (Kihwele et al. 2014).

**Lesser flamingos population**

The number of lesser flamingos drastically lessened from the beginning of the rains in 2010 (Figure 13) from 41,592 in 2010 to 10,168 in 2011 and further lessened to 110 in 2012. This pattern follows that of lessening phytoplankton levels shown in Figure 12.

**Figure 12.** Trend in mean phytoplankton levels in Lake Nakuru from 2009 to 2014
Correlation between alterations in lake conductivity and alterations in population estimates of the phytoplankton and the lesser flamingo

The findings in Table 1 showed that there was a nonsignificant positive correlation between conductivity and phytoplankton, \( r=0.437, p=0.386 \). The findings in Table 2 showed that there was a notable positive correlation between conductivity and the lesser flamingo, \( r=0.767, p=0.075 \). The findings in Table 3 also showed that there was a notable positive correlation between phytoplankton and the lesser flamingo, \( r=0.731, p=0.099 \).

Table 1. Correlation of alterations in lake conductivity to alterations in population estimates of the phytoplankton in Lake Nakuru during the study period (2009 to 2014)

<table>
<thead>
<tr>
<th>Conductivity in (mS/cm)</th>
<th>Phytoplankton (Units/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td>1.437</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.386</td>
</tr>
<tr>
<td>N</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2. Correlation of the alterations in electrical conductivity to alterations in population estimates of the lesser flamingo in Lake Nakuru from 2009 to 2014

<table>
<thead>
<tr>
<th>Conductivity in (mS/cm)</th>
<th>Lesser flamingo water bird</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td>1.767</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.075</td>
</tr>
<tr>
<td>N</td>
<td>6</td>
</tr>
</tbody>
</table>
Figure 10. Time series extent of flooding in Lake Nakuru from a low area of 31.8 km² in January 2010 to a high of 54.7 km² in Sept 2013, a total increment of 22.9 km² (71.9%) (Onywere et al. 2013)

Table 3. Correlation of the alterations in the population estimates of the lesser flamingo in Lake Nakuru to alterations in the population estimates of the phytoplankton from 2009 to 2014

<table>
<thead>
<tr>
<th>Lesser flamingo</th>
<th>Phytoplankton</th>
<th>water bird</th>
<th>correlation</th>
<th>Sig. (2-tailed)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson</td>
<td>1</td>
<td>.731</td>
<td></td>
<td>.099</td>
<td>6</td>
</tr>
</tbody>
</table>

Projections of the climatic data (temperatures, evaporation and rainfall) for the period 2017-2100

Future climate scenarios of Lake Nakuru comprising near surface temperature, rainfall and evaporation were plotted for the period 2017 to 2100 (projection) for RCP2.6 and RCP8.5 relative to the baseline period 1971 to 2000. The results obtained are sequentially propounded in the subsections that follow.

Near surface temperature projections

Future alterations in annual temperature for Lake Nakuru under RCP2.6 and RCP8.5 for the period 2017 to 2100 relative to baseline period 1971 to 2000 are propounded in Figure 14 and 15 respectively.

Temperature projections indicate an accruing trend with a 1.2°C increment for the 2071 to 2100 mean alterations for RCP2.6 (Figure 14) whereas there is a 4.8°C increment for the 2071 to 2100 mean alterations for RCP8.5 (Figure 15). The likely causes of the accruing trend of temperature under both RCP2.6 and RCP8.5 could be due to accruing levels of greenhouse gas concentrations in the atmosphere during the projected period. Notably however, the rate of temperature increment in RCP2.6 is lower than that of RCP8.5.

Rainfall projections

Future alterations in rainfall for Lake Nakuru under RCP2.6 and RCP8.5 were plotted for the period 2017 to 2100 relative to baseline period 1971 to 2000 are shown in Figures 16 and 17 respectively.

The rainfall projection from RCP2.6 and RCP 8.5 show a 10% and 20 % increment in rainfall for the 2071 to 2100.
Evaporation projections

Future alterations in evaporation for Lake Nakuru under RCP2.6 and RCP8.5 for the period 2017 to 2100 relative to baseline period 1971 to 2000 are shown in Figures 18 and 19.

Relative evaporation is projected to raise by 10% and 20% for the 2071 to 2100 mean changes for RCP2.6 and RCP8.5 respectively.

Figure 14. Near surface temperature projection for RCP2.6 for the Lake Nakuru area from 2017 to 2100 shows a 1.2°C increment for the 2071 to 2100 mean alterations

Figure 15. Near surface temperature projection for RCP8.5 for the Lake Nakuru area from 2017 to 2100 shows a 4.8°C increment for the 2071 to 2100 mean alterations

Figure 16. Rainfall projections for RCP2.6 for Lake Nakuru

Figure 17. Rainfall projections for RCP8.5 show a 20% increment in rainfall in Lake Nakuru area for the 2071 to 2100 mean alterations

Figure 18. Relative evaporation alteration for RCP2.6 for the Lake Nakuru for 2071 to 2100

Figure 19. Relative evaporation alteration for RCP8.5 for Lake Nakuru

Discussions

As drawn in Figure 4, it can be concluded that rainfall has increased since 2010 and this may have greatly affected the accruing water levels in lakes as shown by the images obtained from (Onywere et al. 2013). Figure 7 also depicts that the depth of the lake has gradually increased since the beginning of the rain in 2010. This can be strongly associated with increased surface runoff and lake catchment improvements from Njoro, Makalia, Larmudiac and Enderit Rivers as well as from direct rainfall to lakes.
Figures 5 and 6 depict that temperature and evaporation have been raising from 2007 to 2009, the same period when there was little/no rain, and drastically lessened from 2009 to 2010, the beginning of the rainy season. According to Trenberth (2011), an increment in temperature usually leads to an increment in evaporation and therefore drought. Heating about 7% per 1 °C raises the water holding capacity of the atmosphere. This is noticed in studies with temperatures and evaporation raising in 2007 to 2009, which increased the capacity to water retaining of the atmosphere, and thus the beginning of rain in 2009.

According to the IPCC (2007), climate change is clearly more and easily accessed by temperature, although atmospheric moisture changes, atmospheric circulation and rainfall are also ascertained because the overall climate system is generally influenced. The capacity to withstand atmospheric moisture is made increment as temperature becomes higher at a rate of about 7% per °C (Trenberth et al., 2003). Collectively, changes in the hydrological cycle are influenced, in particular, the characteristics of rainfall (type, intensity, amount, duration, frequency) and extremes (Trenberth et al., 2003). The increased water vapor convergence guides to heavier rainfall but a reduction in duration and/or frequency in the weather system, given that the total amount changed a little. Therefore, it can be concluded that a slight increment in temperature induces a tighter hydrological cycle because the evaporation rate is also increased which has a direct impact on cloud formation, since intense rainfall is affected as atmospheric water containment capacity increases, as noticed in 2010.

Seasonal hydrological budget changes greatly affect endorheic lakes that may be extreme at a time, resulting in drastic algal biomass accidents and major changes in community composition as has been noticed in Lake Nakuru.

As more water is added to the lake, it liquidized the mineral concentration thereby lessened the electrical conductivity of the lake. Fresh water has low conductivity. According to the study made in Figure 11, the conductivity level began to decline at 2010, after the start of the rain. The relationship between lake water conductivity and lake depth examined in this study reflects the cycle of concentration and dilution of the lake due to evaporation during the dry season followed by replenishment from river in-flow and water run-off during the wet season. These hydrological cycles have a profound effect on aquatic biota in the lake (Githaiga, 1997).

The correlation coefficient in Table 1 showed changes in lake conductivity and corresponding changes in phytoplankton population estimates. The undistinguished coefficient between conductivity and phytoplankton ($r = 0.437, p = 0.386$) reflects the cycle of lake dilution due to replenishment from the river in-flow and water run-off during the rainy season. Some aquatic species adjusted to life in highly alkaline water at Lake Nakuru and achieved a very high level of biomass that serve as food for the main feeder. The species of blue green algal, *Arthrospira fusiformis* is one such species and it is the main food of the lesser flamingos. Thus, when the level of conductivity of the lake lessened, the rate of phytoplankton in the lake also lessened because the conditions were not conducive for them to bloom.

Table 2 shows that the conductivity had a strong positive correlation, with a lesser flamingo ($r = 0.767, p = 0.075$). This entails that low conductivity impacts the growth of phytoplankton by making an undesirable environment for raising phytoplankton. Because the lesser flamingo relies on phytoplankton for their feed, then it suggests that the denseness of phytoplankton can be a notable predictor of the lesser flamingo occurrence in Lake Nakuru. The noticed correlation which is high and strong ($r = 0.731, p = 0.099$) between phytoplankton and lesser flamingo showed in Table 3 confirms that in saline lakes, the distribution of lesser flamingo is affected by the availability of feed.

Figures 14 to 19 shows an increment in temperature, rainfall and evaporation for the period 2017 to 2100 under RCP2.6 and RCP8.5 relative to the baseline period 1971 to 2000 acquired from the Model Combined Model Intercomparison Phase 5 (CMIP5) multi-model ensemble.

As you will notice, the rising rate in temperature, rainfall and relative evaporation in RCP8.5 are looked to be higher than in RCP2.6. This is assigned to the fact that RCP8.5 is qualified by a business-as-usual scenario with rising greenhouse gas emissions over time, conducing to high levels of greenhouse gas concentrations equated to RCP2.6 which exemplifies an all-out attempt to restrict warming global to below 2°C with emissions declining sharply after 2020 and zero from 2080 onwards.

Based on the rainfall projection (Figures 16 and 17), it is estimated that the average depth of the lake will raise over time because the replenishment is strongly affected by rainfall, which is also positively associated with the temperature. Therefore, an increment in rainfall will result in an increment in discharge during the projection period. As explained before, a slight increment in temperature induces a stronger hydrological cycle, and therefore, because the projection indicates an increment in temperature level, it is estimated that the hydrological cycle will be very strong during the projection period, which assumes that ultimately, the hydrological cycle will be altered, resulting in more intense rain, characterized by thunderstorms (Trenberth 2011).

The raising replenishment during the projection period will make the level of conductivity in the lake to lessen, indicating the increased concentration and dilution cycle of the lake due to evaporation during the dry season followed by replenishment by the river in-flow and water run-off during each wet season. The decrement in conductivity levels will consequently alter the condition of the lake making an unfavorable environment for phytoplankton thrives, thereby cutting down the handiness of feed for lesser flamingos and finally, cutting down the amount of lesser flamingos in lakes due to their migration to other lakes which harbor the food supply of their choice and with the appropriate living conditions.

Based on the fact that the lake area has a negative rain fall/evaporation deficit, the raising temperature will induce a higher evaporation rate and therefore higher conductivity...
due to evaporative concentration, during the projected period.

Conclusions

The study discovered that climate change and climate variability can cause substantial effects on saltwater lakes by making modifications in their physicochemical traits. This has been proved by the variations in rainfall and temperature which affects the phytoplankton availability, ascertained by the chemical and physical traits of the lake. There were fluctuations on the lesser flamingos’ population due to climate variability. These were because of the alterations in rainfall that influenced the physicochemical composition, lake depth, and the surface location of the lake which ultimate effect is discovered in the abundance of the phytoplankton (foods for the lesser flamingos). This study indicates that, the shift and succession in phytoplankton species has a relation with the variations in the physicochemical elements of the lake, especially the conductivity which are greatly affected by the variability of climate. The study also proposes that population dynamics of the lesser flamingos may be affected by using availability of their essential meals, Arthrosira fusiformis which is in turn influenced by physicochemical properties of water and also by weather variability. Based on future projections, it is hoped that the lake will maintain growing in surface area and depth by the year 2100 because of increased thereby influencing the populations of the lesser flamingos and phytoplankton, as the physicochemical elements of the lake will also change in the course of the projected period.

REFERENCES