# ECOLOGY OF LESSER FLAMINGOS *Phoeniconaias minor* (Geoffroy, 1798) IN THE MOMELLA LAKES, ARUSHA NATIONAL PARK - TANZANIA


By

Deogratias Ladislaus Lihepanyama

BSc. Hons (University of Dar es Salaam, Tanzania)


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# DECLARATION

This work is my original research work and has not been presented for a degree or any other award in any other University.

Deogratias Ladislaus Lihepanyama
I56/79610/2012

Signature…………………………………… Date…………………………………

Declaration by supervisors

This thesis has been submitted with our approval as University Supervisors.

Dr.  John Maina Githaiga
Senior Lecturer
School of Biological Sciences
University of Nairobi
P. O. Box 30197 – 00100
NAIROBI
Signature………………………………………….   Date………………………………………

Dr. Francis Mwaura
Senior Lecturer
Department of Geography & Environmental Studies
University of Nairobi
P. O. Box 30197 – 00100
NAIROBI
Signature……………………………………… Date……………………………………....

# DEDICATION

This work is dedicated to my parents Mr. and Mrs. Ladislaus Lihepanyama for their prayers, support and encouragement during the entire period of my studies. I highly appreciate their concern.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ANAPA | Arusha National Park |
| ANOVA | Analysis of Variance |
| APHA | American Public Health Association |
| GDP | Gross Domestic Product |
| IPCC | Intergovernmental Panel on Climate Change |
| IUCN | World Conservation Union |
| ISE | Ion Selective Electrode |
| NRF | Natural Resources Facts |
| NDRS | Ngurdoto Defluoridation Research Station |
| ppt | parts per thousand |
| SPSS | Statistical Package for Social Scientists |
| TANAPA | Tanzania National Parks |
| TAWIRI | Tanzania Wildlife Research Institute |

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## ABSTRACT

This study was carried out in Lake Big Momella and Lake Rishateni found in Arusha National Park (ANAPA) -Tanzania. It explored the factors that influence food availability and habitat utilization of lesser flamingos *Phoeniconaias minor* (Geoffroy, 1798) following their frequent deaths and general population decline in the lakes. The factors included water quality, algal biomass and lake morphometry. Data collection of the variables under study was undertaken on monthly basis during the period between months of November, 2013 and May, 2014.

It was established in both lakes that all physicochemical parameters except salinity and pH showed a significantly positive correlation with algal biomass and proliferation of algal blooms. However, the influence of electrical conductivity, salinity and total nitrogen on algal biomass differed significantly between the two lakes ($F_{1, 13} = 34.578$, $p = 0.005$, $F_{1, 13} = 617.522$, $p < 0.005$ and $F_{1, 13} = 5.975$, $p < 0.031$ respectively). Harmful species e.g. *Microcystis* and *Anabaenopsis* were also identified in the algal blooms from both lakes. Total number of lesser flamingos in Lake Big Momella and Lake Rishateni negatively correlated with algal biomass ($r = - 828$, $p < 0.022$ and $r = - 0.792$, $p < 0.034$ respectively). A negative significant correlation also existed between the total number of lesser flamingos and water depth in lakes Big Momella and Rishateni ($r = - 0.859$, $p < 0.006$ and $r = - 0.875$, $p < 0.004$ respectively). It can be inferred from the findings of this study that shifts in algal biomass, proliferation of algal blooms, the presence of harmful algal species and seasonal fluctuations in water level that contaminated the food and affected habitat utilization could have contributed to the frequent deaths observed and general decline in numbers of lesser flamingos in the lakes. Based on the findings this study recommends protection of the Momella lakes ecosystem by protecting soil, water sources and catchment areas which is important for monitoring good water quality. Identification of specific cyanotoxins that are lethal to the lesser flamingos should also be put into consideration.

# CHAPTER ONE

# BACKGROUND AND LITERATURE REVIEW

## 1.1 Background

Lesser flamingos as documented by Brown *et al.,* (1982) are wading water birds that are found in three sub- Saharan regions namely East Africa, Southern Africa and West Africa. The majority of the lesser flamingos according to Githaiga (2003) are found in Eastern Africa with small population in Southern and Western Africa. In East Africa, lesser flamingos are found in most of the Eastern Rift Valley saline lakes. Their distribution and movements are mainly influenced by food availability which in turn is affected by water quantity and quality (Tuite, 2000, Brown & Root, 1971). In Northern Tanzania, apart from Lakes Natron, Eyasi and Manyara lesser flamingos are also found in Momella lakes ecosystem in Arusha National Park.

Frequent deaths and general decline in the number of lesser flamingos in the Momella lakes have recently drawn the attention of many research studies on lesser flamingo's ecology in that ecosystem. Reports show that there have been frequent deaths and decrease in the number of the lesser flamingos inhabiting Momella lakes ecosystem. The highest death rates of between 15 and 50 flamingos per day were recorded in July and August, 2004. During this time an estimated number of 1050 dead flamingos were counted at Lake Big Momella according to TANAPA (2005). The causes for the mass mortality and decrease in lesser flamingo populations in Momella lakes ecosystem are not yet established, but were suspected to be due to a combination of factors including algal (cyanobacteria) blooms (Lugomela *et al.,* 2006, TAWIRI, 2012).

Other reports show that episodes of mass mortality and decline in total number of lesser flamingos were not confined to Momella lakes alone. During the July and August, 2004 period, about 43,850 lesser flamingo carcasses were recorded in Lake Manyara in Tanzania (TANAPA, 2005). According to Ndetei & Muhandiki (2005), unpredictable incidences of mass mortality of lesser flamingos have previously been reported in the Kenyan Rift valley saline lakes. According to the reports, in 2000, an estimated number of over 30,000 birds died in Lake Bogoria in Kenya. The causes of such massive deaths of lesser flamingos are still unclear but have been commonly attributed to heavy metal pollution, cyanotoxins and fluctuations in water level due degradation of catchment areas and climate variability.

Various studies are being conducted in order to establish the real cause of such high death rates and the general decrease in the number of lesser flamingos inhabiting the Momella lakes. This research based its focus on lesser flamingo feeding and habitat utilization and is intended to establish the relationship of the factors which affect the feeding behavior, utilization patterns and the general decline of lesser flamingos in the Momella lakes ecosystem. The study is based on the premise that food supply, including quantity and quality of food are all governed by water quality parameters, which are therefore the key determinant of the flamingo ecology.

## 1.2 Literature review

Momella lakes are found in Arusha National Park (ANAPA) located in the North Eastern part of Tanzania. There are seven lakes within the Momella lakes ecosystem namely Big Momella, Small Momella, Kusare, Elkotoito, Rishateni, Tulusia and Lekandiro. They form one among the three most significant and attractive features in the park. The other two features include Mount Meru, a prominent volcanic mountain with an elevation of 4566 meters and the Ngurdoto Crater with a diameter of 3.6 km at its widest point and 100 meters deep. Just as the name suggests the Big Momella is the biggest compared to the other lakes in the ecosystem with a length of 9.5 km, mean and maximum depths of 1 meter and 10 meters respectively (Melack, 1976). The lakes are mostly fed by underground streams and underground seepage is supported by rainfall at various times of the year. Momella lakes being alkaline in nature contain blue green algae and invertebrates which attract and support many other water birds species including Maccoa ducks, little grebes, Egyptian geese, herons, greater flamingos and especially the lesser flamingos (Marttila, 2011). Among the seven Momella lakes lesser flamingos are found only in lakes Big Momella, Rishateni and Tulusia as they contain more of the blue green algae.

Other lakes that are found in proximity to the two lakes under study are Lake Kusare which is small, swampy and during the rainy season forms a favorite spot for waterbucks. Lake Elkotoito is surrounded by green hills and often dries up in the dry months to become a pan with little streams, attracting plenty of buffalos, giraffe, zebra and antelopes. Lake Small Momella is found in a valley dotted with green islands and secretive bays where buffalos, water and bushbucks, hippos and a variety of waterfowls can be seen. To the north of lakes Big Momella and Small Momella are lakes Lekandiro and Tulusia. Like Lake Rishateni, Lake Tulusia is also inhabited by lesser flamingos temporarily (Martilla, 2011).

### 1.2.1 Hydrology and geology of Momella lakes

Momella lakes as stated previously are alkaline in nature and are mostly fed by underground hydrological inflow. According to Lugomela *et al.*, (2006) water tables in the Momella lakes ecosystem are supported by rainfall at various times of the year. Previous geological studies indicated that the aquifers are composed of volcanic rocks such as phonolitic and nephelinitic lavas, basalts, lahars of various ages and mantling ash. Sedimentary rocks consisting of fine-grained alluvial and lacustrine deposits occur as well (Ghiglieri *et al*., 2010). According to the findings, the geochemical composition of the water is typically sodium bicarbonate. The ground water recharge, transmission and discharge in Momella lakes are determined by a combination of geomorphology, geology and structural patterns.

The ground water is characterized by a multidirectional flow, dominated by movement from the higher elevation of Mount Meru towards the southern part of the region to the lower lying area in the north. Recharge is through rainfall infiltration and lateral connections to other hydro-geologic units. The cone-shaped relief of Mount Meru generates a general ground water radial flow, which locally is influenced by fracture densities and porosities of the different hydro-geological units (Ghiglieri *et al*., 2010) and both shallow and deep circulating groundwater can be distinguished. Hydro-geologically about 75% of Tanzania, according to Kongola *et al*., (1999), is underlain by crystalline basement complex rocks of variable composition and ages, but predominantly Precambrian, which form the basement aquifers.

Other aquifer types include Karroo, coastal sedimentary formation of limestone and sandstone, and the alluvial sedimentary sequence, which mostly include clay, silt, sand and gravel, and volcanic materials. The groundwater potential of every type of aquifer differs significantly at the local scale as well as at the basin scale. The groundwater potential of each main aquifer type differs significantly from place to place or basin-wise due to variability in aquifer formations and recharge mechanisms. The occurrence of groundwater in Mt. Meru area is largely influenced by geological conditions. Shallow ground water hosted in unconsolidated or semi-consolidated saturated sediments is referred to as local systems. Intermediate and deep groundwater circulation occurs where the permeability of the aquifer and a sufficient elevation difference between recharge and discharge area allow deep infiltration. Deep infiltration is also promoted where widespread fracturing and faulting affects the rock. Where these circumstances prevail, substantial precipitation levels can support productive wells and springs (Ghiglieri *et al*., 2010).

Typically, silicate minerals and glass present in alkaline lava and ash are weathered by hydrolysis, producing Sodium bicarbonate ($NaHCO_3$) rich and Calcium ions ($Ca^{2+}$) and Magnesium ions ($Mg^{2+}$) depleted groundwater (Jones *et al*., 1977). This process affects the degradation of phonolite, tephrite-phonolite, Na-K-feldspar and Na-Kfeldspatoid, which occurred in the lahar formations. Ground waters, particularly those containing dissolved Carbon dioxide ($CO_2$), react readily with alkaline silicate such as albite to release sodium and bicarbonate ions. This process appears to be commonplace in the NE-SW-trending fault system on the eastern flank of Mt. Meru, where the most suitable hydrothermal conditions occur. According to the findings such as those by Jalali, (2007) the alkalinity of groundwater as well as that of Momella lakes is therefore associated with the presence of alkali metals, as he demonstrated by the positive correlation that exist between alkalinity (bicarbonate content) and Sodium and Potassium ions ($Na^+$ and ($K^+$) concentrations.

### 1.2.2 Taxonomy and distribution of lesser flamingos

Systematic classification and taxonomy place lesser flamingos into Phylum: *Chordata,* Class: *Aves,* Order: *Ciconiiformes,* Family: *Phoenicopteridae* and Genus: *Phoeniconaias* (Geoffroy, Saint-

Hilaire, 1798). Momella lakes being alkaline in nature support large numbers of lesser flamingos that feed on the blue green algae *Arthospira fusiformis* which forms the main diet for the lesser flamingos. Thus, it becomes important when studying ecology of lesser flamingos in such ecosystems factors like water quality, food supply, quality and quantity as well as lake morphometrics are crucial as they affect the feeding ecology and lake utilization patterns of lesser flamingos. In addition lesser flamingos are associated with nomadic movements between various alkaline lakes. Their movements and distribution between the saline lakes are spontaneous and unpredictable, but have been shown by many research studies to be closely associated with the chemistry of water, food quality, food quantity and breeding seasons (Githaiga, 2003, Tuite, 1978). Therefore any change with regards to the chemistry of the water, food quality and quantity is enough to make them shift from one saline lake to the other.

### 1.2.3 Threats to lesser flamingos

According to the IUCN (2012), Red List the lesser flamingos are classified as Near Threatened Species. This is because of their restricted breeding sites, degradation of their specialized breeding sites and feeding habitats due to pollution, mining, agro-industry and siltation (Collar *et al.*, 1994). Other threats to the survival of the lesser flamingos include: altered hydrology and water quality, infectious diseases, predators (e.g. Marabou Stork; *Leptoptilos crumeniferus*), intentional poisoning, intentional wildlife trade, harvesting of eggs and live birds, habitat loss and degradation, competition for food and breeding sites, extraction of salt and soda ash especially in the breeding sites, destruction of breeding and nesting colonies by other anthropogenic activities.

Another threat to the survival of the lesser flamingos is climate change. According to IPCC (2001), climate change refers to persistent fluctuations of the climatic parameters especially temperature, wind, clouds, humidity and precipitation for a sufficiently long time and these anomalies are statistically noticeable and significant. Climate change has recently been a major issue because of the close relationship that exists between climate and the survival of many species. Birds are among the groups of animal species on which the impact of climate change on their migrations and breeding have already been noted. In this case lesser flamingos are not spared since the parameters of climate change affect water quality as well. Some significant impacts due to climate change have already been noticed and they include; changes in species distribution, changes in population sizes, events pertaining to reproduction or migrations and increased frequency of pests and diseases outbreaks (UNEP, 2006).

With regards to their distribution, lesser flamingos are widely distributed in most of the alkaline lakes in Eastern Africa. Those found in the Rift valley in Kenya and Northern Tanzania constitutes about 15% of the global population (Tuite, 1978). The current population of lesser flamingos is estimated to be 1.5 to 2.5 million birds in all 9 alkaline - saline lakes of the Great Rift Valley in East Africa. Lake Natron is by far the most significant breeding site for the East Africa lesser flamingo population while the Momella lakes form one among the most important feeding sites in Tanzanian (Tuite, 1979).

Morphologically lesser flamingos are differentiated from the greater flamingos by their smaller size and color. The lesser flamingos are pinkish/white and smaller in size weighing up to 2 kgs with lifespan of between 30 to 40 years. The bill is dark carmine red with a downward curve and a black tip, which looks entirely black in the field. They are normally found in large or small groups depending on the size of the population as documented by Marttila (2011). On the other hand greater flamingos are bigger in size than the lesser flamingos weighing up to 4.5 kg with a life span of over 60 years. The colour of the bill is pink with a restricted black tip. The pink coloration in the greater and lesser flamingos comes from the carotenoid pigments contained in the foods that they feed as shown in plate 1.1

**Lesser flamingos (*Phoeniconaias minor*)**

**Greater flamingos (*Phoenicopterus roseus*)**

**Plate 1.1:** Morphology of lesser flamingos

### 1.2.4 Lake Morphometry (water depth)

Lake morphometry is among the important factors which affect the feeding behavior and habitat utilization by lesser flamingos in any ecosystem. This refers to the shape, structure and size of a lake basin and also includes the determination of water depths which is crucial for the utilization ecology of the lesser flamingos. This factor is as significant as other lake characteristics with regards to the feeding and utilization ecology of the lesser flamingos. Morphometric factors such as water depth, surface area, and length of the shoreline and area- shoreline ratio according to the findings by Mwaura (2009), are among the factors that strongly influence not only birdlife population but also species diversity. Such factors are very important as they regulate lakes' chemo-thermal-dynamics, which in turn influences many other ecological processes.

The shape and structure of a lake basin can provide significant knowledge on how a lake functions and one can sometimes predict how weather conditions or human-induced events may affect water levels and quality in the ecosystem. This study focussed only on one aspect of morphometrics and that is water depth variability because changes in water levels can affect water quality, food supply, quantity and its quality including the amount of algae and/or aquatic plants growing in the water, fish species and their abundances. In addition to that, previous studies of algae, aquatic invertebrates and fish populations have shown that shallow lakes are generally more productive than deep lakes because of the potential for waves to re-suspend bottom sediments (Florida LAKEWATCH, 2001).

Shallow lakes which are considered to be less than 15 feet (4.57 m) in depth usually allow sufficient light penetration to the lake bottom where the majority of aquatic plants are found. Lakes with greater depths do not usually experience adequate vertical mixing of bottom sediments as shallow lakes. This is because wave action is less likely to reach the bottom and enhance mixing of bottom nutrients. Based on this concept lake morphometrics have profound effects on the feeding and habitat utilization behavior of lesser flamingos. Because of their specialized diet of microscopic alkaline blue green algae lesser flamingos are totally dependent on shallow alkaline lakes, wetlands, pans and coastal areas.

### 1.2.5 Lesser flamingo habitat characteristics

Good feeding habitat for the lesser flamingos is crucial for species support. The key habitat attributes include appropriate water chemistry, which enables the growth of diatoms and blue green algae, and several hours of sufficient calm each day for the lesser flamingos to feed. Lesser flamingos subsist mainly on blue green algae *A. fusiformis* with occasional resort to benthic diatoms. They extract their food by filtering and because of that they are termed as algivorous filter feeders. This unusual mode of feeding is enabled by the modification of their bill structures. The modified bill structures allow them to pump water quickly into the filtering system for food extraction at a constant volume rate of 31.8 l/hr (Githaiga, 2003; Tuite, 1978; Jenkin, 1957).

*A. fusiformis* is one of the many species of blue green algae. Blue green algae commonly known as cyanobacteria are prokaryotic photosynthetic organisms which grow well in water bodies with high temperature, intense light, high water pH and high availability of nutrients especially phosphorus and nitrogen (Purves *et al.*, 2003). Blue green algae can tolerate huge changes in salinity and temperature. However when favorable conditions prevail, such as high temperature, intense light, high pH and increased availability of nutrients particularly phosphorus and nitrogen in polluted water bodies, this species tend to flourish rapidly forming algal blooms that are also resilient and are able to withstand unfavorable conditions as spores (Giliane and Oliveira-Filho, 2013).

Proliferation of algae as a result of excess nutrients in water has many ecological impacts on the feeding and utilization patterns of lesser flamingos and other aquatic organisms. The blooms affect not only the spatial and temporal distribution but also the quality of food for lesser flamingos (Lugomela *et al.*, 2006). Algal blooms however, interfere with the use, enjoyment of lakes by societies around the world and decrease aesthetic beauty by reducing the water quality in terms of color and smell, altering species composition and often creating bad taste and unpleasant odor (William, 1999). Algal bloom spores thus often contaminate food for lesser flamingos and can adversely impair their health and survival.

Cyanobacteria which are best known as the dominant species of most algal blooms can produce a variety of toxins collectively known as cyanotoxins. The toxins are functionally classified into neuro-, hepato- and cytotoxins depending on which part of the animal's body they affect (Giliane & Oliveira-Filho, 2013). Some cyanobacteria e.g. *Microcystis spp.* produce cyanotoxins which, when present in high concentration, have the potential to kill not only the lesser flamingos, but also other animals. Species like *Microcystis* often produce neurotoxins with different modes of blocking neuronal signal transmission (anatoxin-a, anatoxin-a(s) and saxitoxins. Among the toxic effects is from one general cytotoxin called cylindrospermopsin which inhibits protein synthesis, while a group of toxins termed microcystins (or nodularins, found in brackish waters) inhibit protein metabolism (Giliane & Oliveira-Filho, 2013

The mass mortalities of lesser flamingos in Momella lakes ecosystem are suspected to occur due to algal blooms containing harmful cyanobacteria which tend to mix up with *A. fusiformis,* a species which forms the main diet for lesser flamingos (Lugomela *et al.,* 2006,). Unfortunately, other studies done in Lake Bogoria in Kenya by Ballot *et al*., (2004), observed that *A. fusiformis* isolated from the lake could produce both microcystins-YR and anatoxin-*a* that are all harmful to the survival of the lesser flamingos. However, research are still going on to find out if there is also toxic and non toxic *A. fusiformis* in other African saline lakes and at what concentration they can be harmful to the lesser flamingos. With regard to the physical effect of algal bloom proliferation, a lot of shade is generated and it blocks sunlight from reaching rooted aquatic plants, limiting their growth or even causing them to die (Lugomela *et al*., 2006, Carmichael *et al.*, 1995).

As more algae grow within lakes, there are also more dead algae to be decomposed. Decomposition of algae by bacteria consumes a lot of oxygen and can decrease or even completely deplete dissolved oxygen content thereby inducing anoxic or hypoxic conditions. These conditions lower the water quality of the lake (NRF, 1996). It is therefore evident that any ecological process affecting water quality, food quality and quantity either due to increased siltation or pollution from anthropogenic activities poses a major threat to the survival of the lesser flamingos. Changes in water quality, food quality and quantity in most of the alkaline lakes that are not well protected can easily trigger lesser flamingos' movement instincts (Nyaga & Githaiga, 1999). Rapid growth of algal blooms like in any other polluted lakes can also be a major threat to lesser flamingos inhabiting lakes as they tend to hamper their feeding, making them unable to utilize some portions of the lakes (TAWIRI, 2012, Lugomela *at al*., 2006).

## 1.3 Problem statement

The adverse conditions and the relationship of the variables that affect the feeding behavior and habitat utilization of lesser flamingos in Momella lakes ecosystem has not yet been documented. The variables include: algal biomass, species composition, water quality and morphometry (water depth). This problem raises the need for taking responsibility in preserving saline lakes and all other lakes regardless of their sizes in order to ensure the continued survival of this Near-Threatened Species (IUCN, 2012) and other water bird species. And according to TAWIRI (2012), there are various reasons warranting the study of lesser flamingo feeding and habitat utilization ecology in the Momella lakes ecosystem. The observations are a) frequent deaths of lesser flamingos whose cause is suspected to be integrated factors including cyanobacteria toxicity, b) observed failure of the lesser flamingos to utilize some portions of the lakes and c) the general decline in number of the lesser flamingos inhabiting the lakes. As such, scientific studies are being conducted in Momella lakes ecosystem. This study was part of the effort to establish the causes of the mass mortality, restricted use of some portions of the lakes and the general decline in the number of the lesser flamingos inhabiting the lakes.

## 1.4 Justification

According to the Report by Tanzania National Single Species Action Plan (2010), the conservation of lesser flamingos in the Momella lakes is important for sustainable management of natural resources and biodiversity, so as to sustain ecosystem functions. Besides, these ecosystems contribute to the economic development of Tanzania through tourism. The lesser flamingos found in the Momella lakes are within the Arusha National Park. This forms a component of Tanzania's circuit tourism course. Reports by World Tourism and World Travel Council Data (2013) showed that travel and tourism contributed about 12 percent of the Tanzania GDP which is equivalent to US $ 4.48 billion. According to the report about 11 percent of the country's labor force employment (1,189,300 jobs) was offered by this sector. The lesser flamingo found in the Momella lakes ecosystem form one among the many tourists' attractions located in the northern part of Tanzania whose contribution to the economic development in the country is crucial. It was therefore necessary to undertake pertinent studies such as the current one because the presence of lesser flamingos in the Momella lakes ecosystem in Arusha National Park is important not only for the conservation of biodiversity in that ecosystem, but also for eco-tourism.

## 1.5 Objectives of the study

### 1.5.1 Overall objective

The purpose of this study was to establish the relationship between abundance of food resources and feeding behavior of lesser flamingos in lakes Big Momella and Rishateni.

### 1.5.2 Specific objectives

The specific objectives were to;

i. Determine the effect of water pH, temperature, electrical conductivity, dissolved oxygen, light transparency, salinity, total nitrogen and total phosphorus on seasonal variation in algal biomass.

ii. Establish how temporal and spatial distribution of lesser flamingos is influenced by algal biomass.

iii. Determine if lake morphometry (water depth) influences habitat utilization by lesser flamingos.

## 1.6 Hypotheses

i. Physicochemical parameters of water pH, temperature, electrical conductivity, dissolved oxygen, light transparency, salinity, total nitrogen and total phosphorus significantly accelerate variations in algal biomass.

ii. Temporal availability and spatial distribution of lesser flamingos is significantly influenced by algal biomass.

iii. Fluctuations in water level significantly alter total number of lesser flamingos as well as habitat utilization patterns.

# CHAPTER TWO

# MATERIALS AND METHODS

## 2.1 Study area

This study was conducted in Lake Big Momella and Lake Rishateni located on the Eastern part of Arusha National Park, Tanzania. The lakes are found on the slopes of Mount Meru between longitudes 36$^o$ 55’ E and latitudes 3$^o$ 12’ S**,** total area of 10 km$^2$ and an altitude of 1450 m. Average annual rainfall in the area is about 900 mm. Temperature in the area varies between 12 – 28 $^0$C depending on the altitude and time of the year (Marttila, 2011). The Big Momella lake is located between latitude: 3°13'22.08" S and longitude: 36°54'33.48" E and has a length of 9.5 km. It is inhabited by the lesser flamingos almost throughout the year and accommodates the largest number of lesser flamingos compared to other Momella lakes. It has a mean and maximum water depth of 1 and 10 meters respectively (Melack, 1976).

Next to Lake Big Momella is Lake Rishateni located between latitude: 3°13'57" S and longitude: 36°54'34" E and has a length of 3.49 km. Unlike the Big Momella, it is temporarily inhabited by lesser flamingos. As explained previously the other lakes that are found in proximity to the two lakes under study are Kusare, Elkotoito, Small Momella, Lekandiro and Tulusia. Like Lake Rishateni, Lake Tulusia is also inhabited by lesser flamingos temporarily (Martilla, 2011). Since the lakes are located very close to border of the park there is a high land use pressure from the local people around the area. There is a high rate of land degradation through anthropogenic activities such as uncontrolled agricultural activities and animal keeping that are done in the catchment area. In a number of occasions the local people around allow their cattle to cross the border of the park and graze around the park causing uncomfortable conditions to the lesser flamingos in the lakes. The locations of lakes Big Momella and Rishateni are shown in figure 2.1

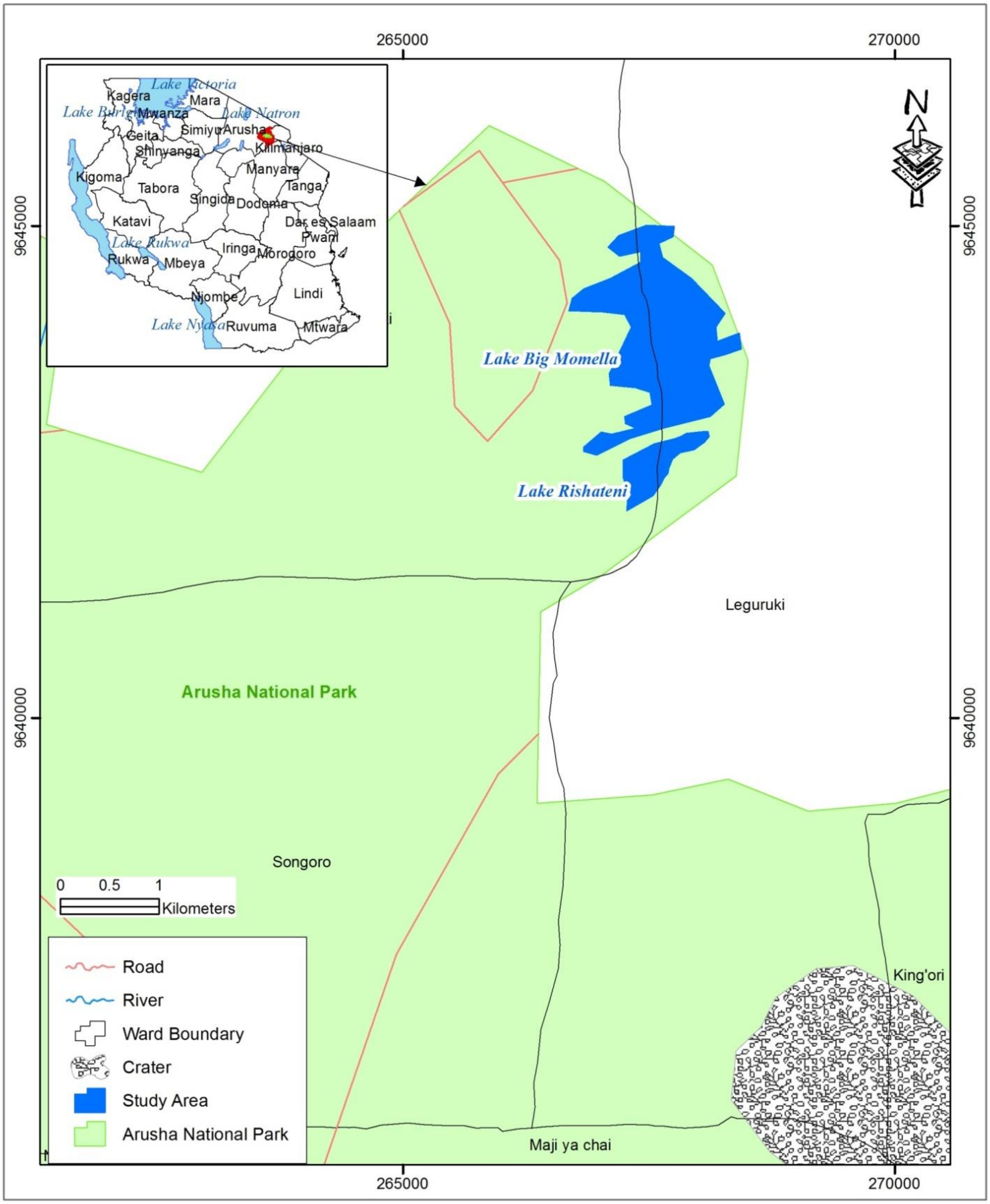



**Figure 2.1**: Locations of lakes Big Momella and Rishateni in Arusha National Park (adopted from Institute of Resource Management, University of Dar es Salaam).

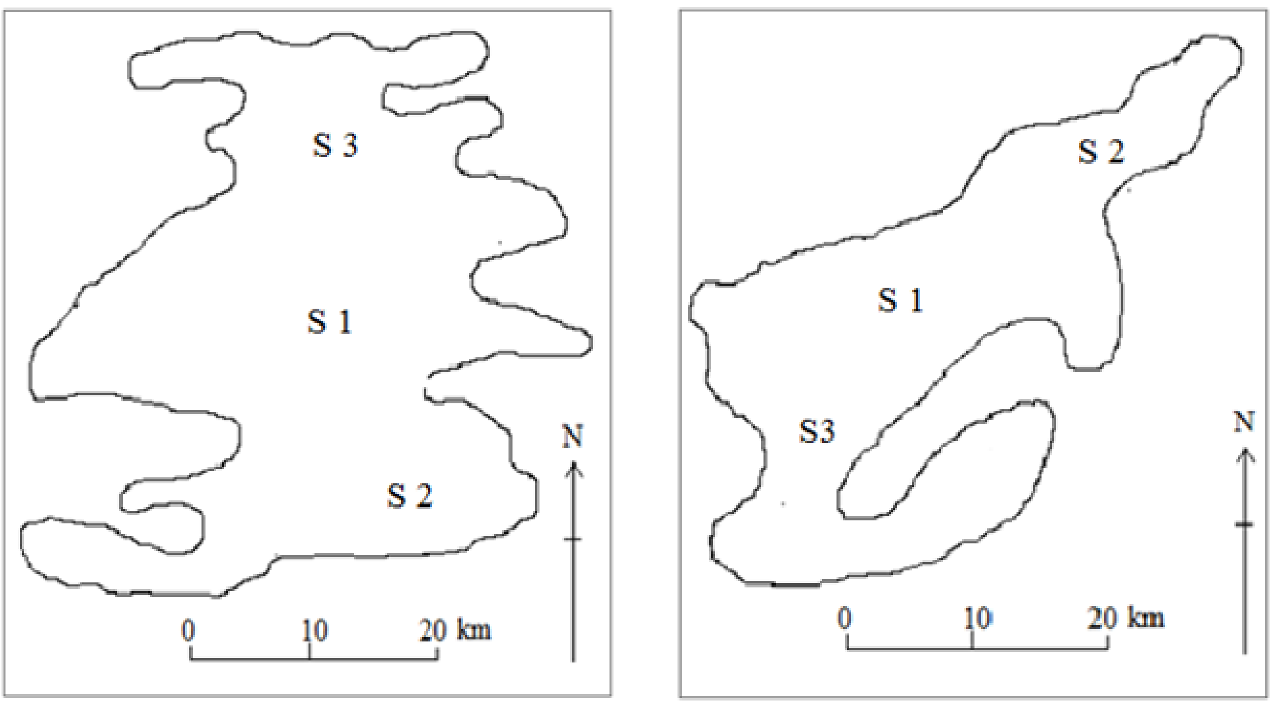
## 2.2 Materials and methods

### 2.2.1 Field data collection

Data collection was undertaken on monthly basis during the period between months of November, 2013 to May, 2014 following the procedures described below.

### 2.2.2 Sampling design

Selection of the sampling sites was based on the locations utilized by lesser flamingos, shoreline configuration, accessibility and safety (Githaiga, 2003). The number of sampling sites was determined based on the size of the lake as suggested by Deborah (1996) and all the sites selected for sampling were georeferenced using a GPS receiver as illustrated in figure 2.2.




Lake Big Momella Lake Rishateni

**Figure 2.2**: Locations of sampling sites in lakes Big Momella and Rishateni (Source: Google *Imagery © 2014 Cnes / spot Image, Digital Globe*).

Thus there were three sampling sites in each lake of which two were inshore and one offshore. The inshore sampling sites were situated at deeper locations to avoid contaminations from the shores. Accessibility to the sampling sites for *in situ* determination of water parameters, collection of water samples and water depth measurements was facilitated using a canoe.

### 2.2.3 Lesser flamingo counts

Ground Census Method was used to estimate the lesser flamingo numbers and this was done on monthly basis. The counting was done from the shoreline by standing on elevated points. The shoreline was divided into four sections for easy counting from the selected elevated points. Telescope (Orion Go Scope II 70 mm) and binoculars (Orion Delux 8 x 42) were also used for easy identification of individual birds as recommended by Bennum & Nasirwa, (2000), Bibby *et al.*, (1998), Arengo & Baldassare, (1995). Since lesser flamingos tend to conceal each other when they are large flocks the instruments minimized biases due to double counting or obscurity as they helped to focus and zoom easily large flocks of lesser flamingos during counting (Githaiga, 2003).

### 2.2.4 Lake morphometry with respect to water depth

Determination of the effect of lake morphometry particularly seasonal fluctuation of water on the utilization ecology of the lesser flamingos was done by using a simple technique of measuring water depths as recommended by Florida LAKEWATCH, (2001). This was done at a number of locations following the established inshore and the offshore sampling sites using a weighted (0.5 kg) string marked in meters. Three water depths measurements were taken from each sampling site for the purpose of improving the reliability of the results. On the other hand the water gauge established at one point along the shore in Lake Big Momella also provided a good means of estimating changes in shoreline water depth as shown in plate 2.1


**Plate 2.1:** Water gauges established along the shore line of Lake Big Momella

### 2.2.5 Water quality

Physicochemical parameters refer to physical and chemical variables that are employed to test the quality of water for a particular purpose. The variables normally provide useful information on the physical and chemical characteristics of the quality of water tested for a particular purpose. The physicochemical parameters measured in this study were water pH, temperature, electrical conductivity, dissolved oxygen, salinity, total nitrogen and total phosphorus. With the exception of total nitrogen and total phosphorus which were determined in the laboratory, the rest of the parameters were determined *in situ* using portable calibrated electronic equipment.

Water pH was determined by a portable calibrated digital Orion 4 STAR pH/ISE Meter, electrical conductivity was determined by using a portable digital HACH- SensION5 Water Proof Conductivity Meter built in with auto-temperature and salinity readings, dissolved oxygen was also determined by a portable calibrated digital HACH – SensION6 Dissolved Oxygen Meter and light transparency was measured using a 20-cm diameter Secchi disc. A 1 liter Water Sampler was used to obtain water samples at different water depths (from 2 to 10 meters) for analysis in order to capture variations that are important in predicting productivity levels in the lakes. Vertical determination of water pH, conductivity, dissolved oxygen and temperature was also done *in situ* in the sampling sites that were offshore.

With regards to the analyses of total nitrogen and total phosphorus, triplicate surface water samples were taken for analyses at Ngurdoto Defluoridation Research Station laboratory using appropriate analytical procedures including those stipulated in APHA (1998). Total phosphorus was analyzed using the Acid Persulfate Digestion Method followed by Ascorbic Acid Method. Total nitrogen was analyzed in all its forms by using Nessler Method, Diazotization Method and Ion Selective Electrode (ISE) for assessment of ammonia, nitrites and nitrates respectively.

### 2.2.6 Algae sampling

Three triplicate surface water samples were collected on monthly basis from November, 2013 to May, 2014 at each sampling site. The water samples were collected from the sampling sites using special sterile 500 ml bottles. A cool box was used to preserve and transport the samples for laboratory determination of algal biomass and species identification as recommended by Deborah (1996). Species counting per field of view was also done for the purpose of establishing which lake is more diverse than the other in terms of microalgae composition.

## 2.3 Laboratory analysis

All laboratory analyses were undertaken at Ngurdoto Defloridation Research Station in Arusha, Tanzania and the School of Biological Sciences, University of Nairobi in the period between November, 2013 and May, 2014 using the procedures explained below.

### 2.3.1 Total phosphorus determination (mg/l)

Total phosphorus was determined by Acid Persulfate Digestion Method followed by Ascorbic Acid Method. The determination involved two methods because phosphates must first be converted to reactive orthophosphate before analysis as they are normally present in organic and inorganic forms (meta, pyro or other polyphosphates). Thus organic phosphates were first converted to orthophosphates by heating with 5.25 N sulfuric acid and potassium persulfate. This pretreatment of the sample with the acid and the heating provides good conditions for the hydrolysis of the condensed inorganic forms. This was then followed by one of the reactive phosphorus methods; Ascorbic acid (PhosVer 3) method to determine the concentration of phosphorus.

Therefore 25 ml of the water sample were put into a 50 ml Erlenmeyer flask followed by the addition of the contents of one Potassium Persulfate Powder pillow and swirled to mix. Thereafter 2.0 ml of 5.25 N sulfuric acid solutions were added to the sample. The mixture was then boiled gently on hot plate for 30 minutes and allowed to cool to room temperature. 2.0 ml of 5.0 N sodium hydroxide solutions were added and swirled to mix. The sample was then poured into a 25 ml graduated cylinder and the volume returned to 25 ml. Determination of phosphorus content of the sample was then determined by using DR/2000 spectrophotometer at a wavelength of 890 nm.

### 2.3.2 Total nitrogen (TN) determination (mg/l)

Nitrogen exists in nature in three forms which include ammonia, nitrites and nitrates. Therefore TN concentration was obtained as a summation of the amount of nitrogen determined from each of the three forms in which nitrogen exists. Procedures for the determination of nitrogen content from each of the three forms in which nitrogen exists are described below;

#### 2.3.2.1 Ammonia nitrogen ($NH_3$-N)

This was determined by Nessler Method. 25 ml of the prepared sample and 25 ml of deionized water (the blank) were filled into 25 ml mixing graduated cylinder respectively. Three drops of Mineral Stabilizer were put to each cylinder containing the sample followed by the addition of three drops of Polyvinyl Alcohol Dispersing Agent. The contents were then mixed with 1.0 ml of Nessler Reagent. Polyvinyl Alcohol Dispensing Agent helps in color formation during the reaction of Nessler reagent with ammonium ions. The nitrogen in ammonia of the sample was then directly determined by using DR/2000 Spectrophotometer at a wavelength of 425 nm after allowing the contents to react for one minute.

#### 2.3.2.2 Nitrite nitrogen ($NO_2$-N)

Diazotization Method was used to determine the nitrite nitrogen content of the sample. 25 ml of the sample (the blank) were put into one sample cell and another sample cell was filled with 25 ml of the prepared sample whose nitrite content was to be determined. One pillow of NitriVer 3 Nitrite Reagent Powder was then added to each sample. The contents were then shaken to dissolve the NitriVer 3 powder. Nitrite nitrogen content of the sample was directly determined by using DR/2000 Spectrophotometer at a wavelength of 507 nm after allowing the contents to react for 15 minutes.

#### 2.3.2.3 Nitrate nitrogen ($NO_3$-N)

This was directly determined using Ion Selective Electrode (ISE). Nitrate ions in the prepared samples are selectively absorbed by the ISE membrane which in turn establishes a potential directly proportional to the concentration of nitrate in the samples.

### 2.3.3 Algal biomass (µg/l)

This was determined by measuring chlorophyll *a* concentration. The measurement was based on the standard method recommended by APHA (1989). In this method 200 ml of the raw water samples were measured using a graduated cylinder after shaking and quickly introduced into filtering apparatus. Whatman filter papers (0.45 µm) were used to filter the samples. While there were still about 5 ml of water left in the filter tower, 10 ml of well shaken Magnesium carbonate ($MgCO_3$) suspension were added to avoid chlorophyll *a* degradation prior to analysis. The filtrate was removed and placed into a tissue grinder tube followed by an addition of 5 ml of 90% acetone. The filtrate was then ground vigorously for approximately 30 seconds. The contents were then put into a 15 ml centrifuge tube. The pestle and the grinding tube were rinsed with the 90% acetone and the contents again put into the centrifuge tube.

The extracts were then centrifuged for 15 minutes at a medium speed (500 r/ min). The volume of extract in the centrifuge tube was recorded. The extract was then filled in a cuvette of 10 cm path length ready for reading the absorbance using DR 2000 spectrophotometer at 750 nm (turbidity blank) and 665 nm before acidification. After recording the first readings at 750 nm and 665 nm respectively, the extracts in the cuvette were then acidified with 25 µl (one drop) of 2N HCl. This reaction was allowed to proceed for about 1 minute before re-reading the absorbance at the previous wavelengths. Upon acidification the magnesium ion is lost from the porphyrin ring, resulting in the production of a phaeophytin (Lorenzen, 1967). The cuvettes were then rinsed with acetone and shaken dry before they were used with the next samples. Therefore the absorbance readings taken at 750 nm and 665 nm respectively before and after acidification were used to determine algal biomass (µg/l) of the samples using the following equation;

$$\text{Algal biomass} \quad (\mu g/l) \quad = \quad 29.6 \left[(E_b665 - E_b750) - (E_a665 - E_a750)\right] \text{X ev} / (\text{V x P})$$

Where:

| | | |
|---|---|---|
| Ea | = | absorbance, acidified |
| Eb | = | absorbance, base |
| ev | = | volume of acetone used in extraction in ml |
| V | = | volume of filtered sample in liters |
| P | = | path length (10 cm path length) |

### 2.3.4 Algal species identification

Algal species identification from the water samples and scum taken from Lakes Big Momella and Rishateni was done using a digital microscope (LAS EZ version 1.8.0) at x100 and x400 magnification during which identification of species. Species counting per field of view and microscopic photographs of the specimen were also taken. Identification process was done with the help of algae identification manuals (Getrud & Helene 2006; Bellinger, 1992; Barber & Harworth, 1984).

## 2.4 Data Analysis.

Statistical data analyses was done using SPSS version 20 Software program. All statistical analyses have been done at 95 % confidence level. Shapiro Wilk (1965) ($P > 0.05$), Skewness and Kurtosis ($\pm 1.96$) tests for normality were employed prior to analyses to ensure normality of the data. Pearson Correlation (r) was employed to test for significant relationships between algal biomass and lesser flamingo abundance in the selected lakes. It was again employed to establish significant associations between morphometrics (water depth) and total number of lesser flamingos and between water quality variables and seasonal variation of algal biomass. Analysis of Variance (ANOVA) was employed to determine whether there were significant variations in algal biomass between seasons and among the sampling sites.

# CHAPTER THREE

# RESULTS

## 3.1 Physicochemical parameters.

### 3.1.1 Amount of rainfall

The trend shows that there were notable variations with regard to average amount of rainfall received in the area during the study period. It was observed that the lowest amount of 78 mm and the highest amount of 1874 were received in January and April, 2014 respectively. November, and December, 2013 received an average amount of 716 mm and 1694 mm respectively. On the other hand February, March and May, 2014 received an amount of 1120 mm, 118 mm and 1395 mm respectively as illustrated in figure 3.1.

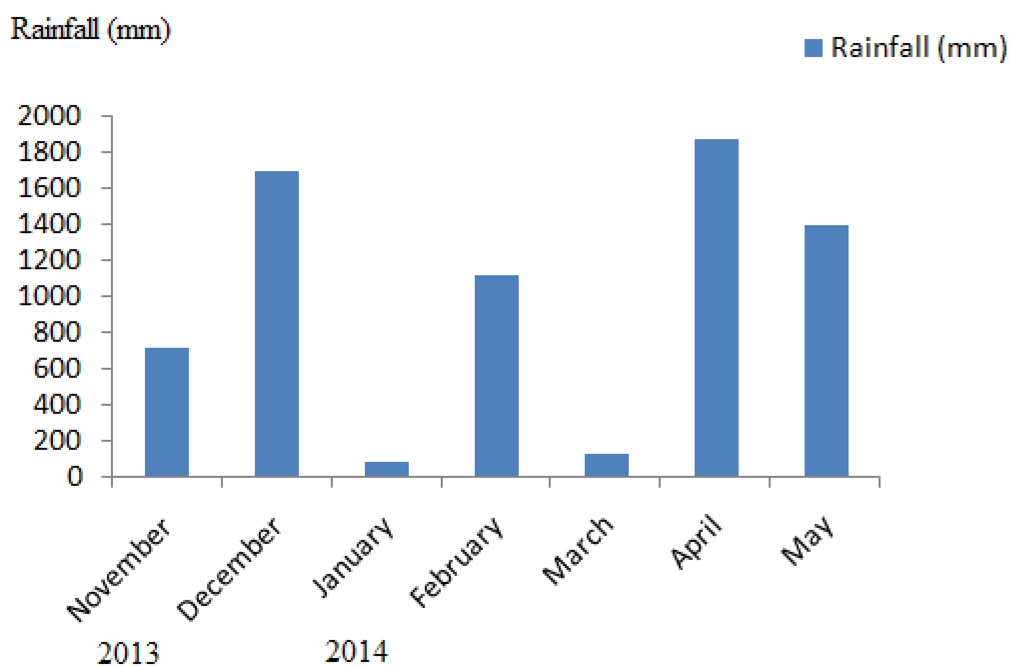



**Figure 3.1:** Monthly average amount of rainfall received in the study area from November, 2013 to May, 2014

### 3.1.2 Physical parameters

In was observed in Lake Big Momella and Lake Rishateni that pH remained fairly constant by ranging from 9.9 to 10. Salinity also behaved in the same manner by ranging from 25.4 to 26.8 ppt. and from 18.4 to 19.4 ppt. in Lake Big Momella and Lake Rishateni respectively. However, the amount of salinity was higher in Lake Big Momella than in Lake Rishateni. The trend with respect to the other physical parameters displayed considerable monthly variations. In Lake Big Momella, for instance, water temperature varied from 23.2 to 27.6 $^{0}$C, electrical conductivity from 34951.1 to 40955.6 µS/cm, dissolved oxygen from 12.2 to 17.7 $mgO_2/l$ and light transparency from 28.3 to 40.3 cm as shown in figure 3.2.

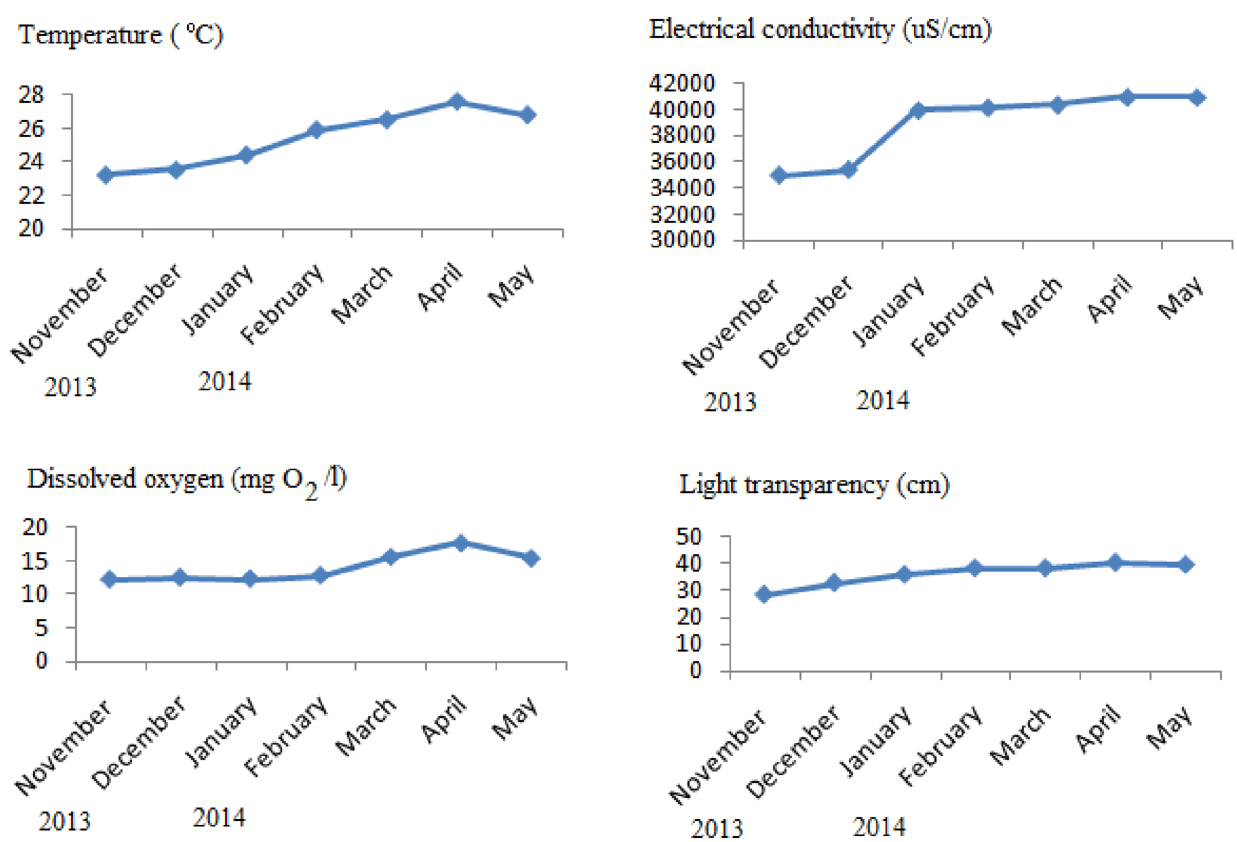



**Figure 3.2:** Monthly changes of various water parameters in Lake Big Momella from November, 2013 to May, 2014.

On the other hand in Lake Rishateni water temperature varied from 24.5 to 28.1 $^{0}$C and light transparency from 25.5 to 40.2 cm, electrical conductivity from 24378.4 to 33115.7 µS/cm and dissolved oxygen from 4.9 to 20.6 $mgO_2/l$ as shown in figure 3.3.

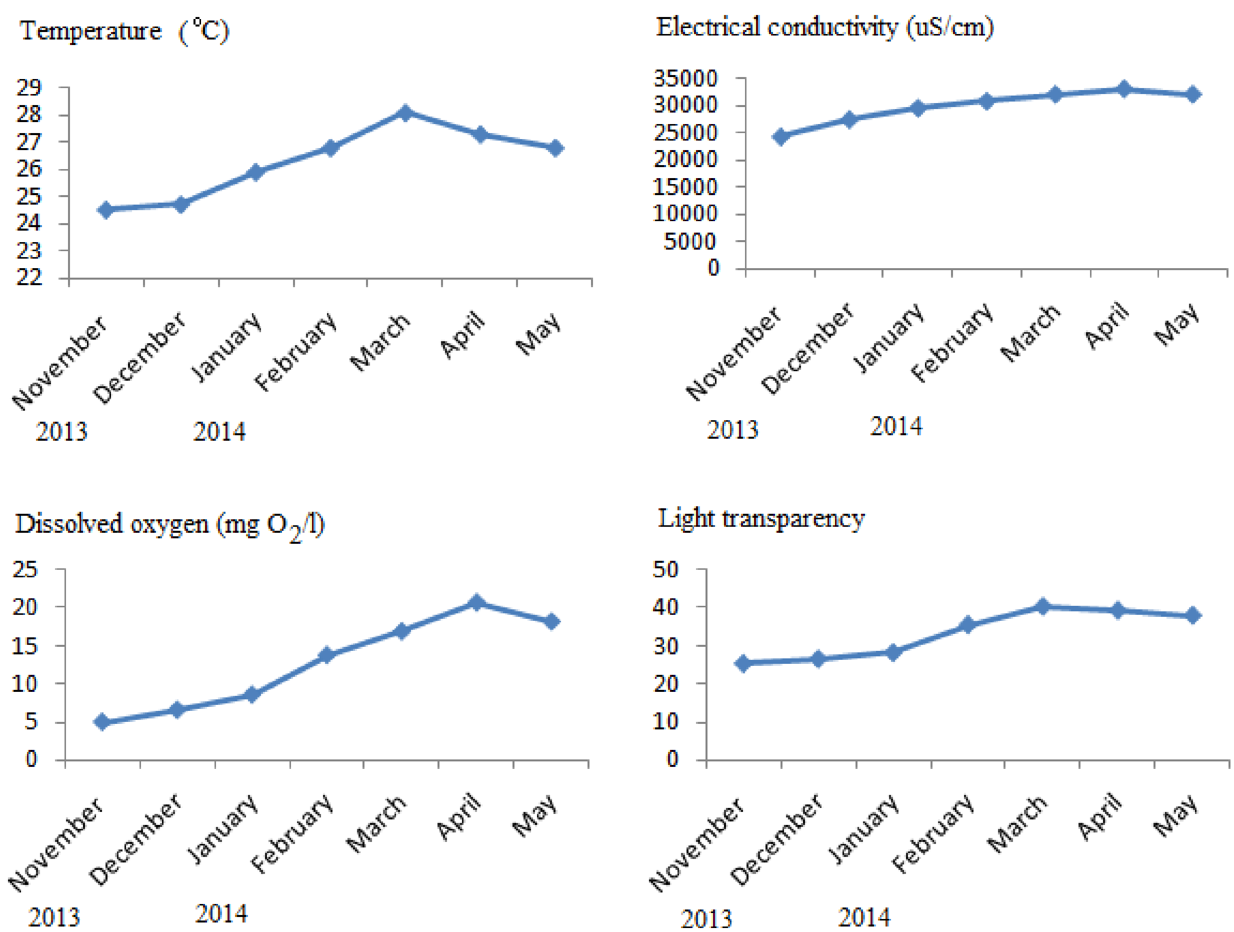



**Figure 3.3:** Monthly changes of various water parameters in Lake Rishateni from November, 2013 May, 2014.

### 3.1.3 Vertical patterns of selected physical parameters

#### 3.1.3.1 Lake Big Momella

The selected water parameters showed great variations with water depth in Lake Big Momella especially in November, 2013 and March, 2014. In November, 2013 pH remained fairly constant down the water column to a depth of 8 meters. All the other selected parameters showed great variations with water depth. Water temperature dropped vertically from 24.9 to 21.9 $^{0}$C, electrical conductivity from 39500µS/cm to 39400µS/cm and dissolved oxygen from 3.6 to 3.2 mg $O_2$ /l as illustrated in figure 3.4.

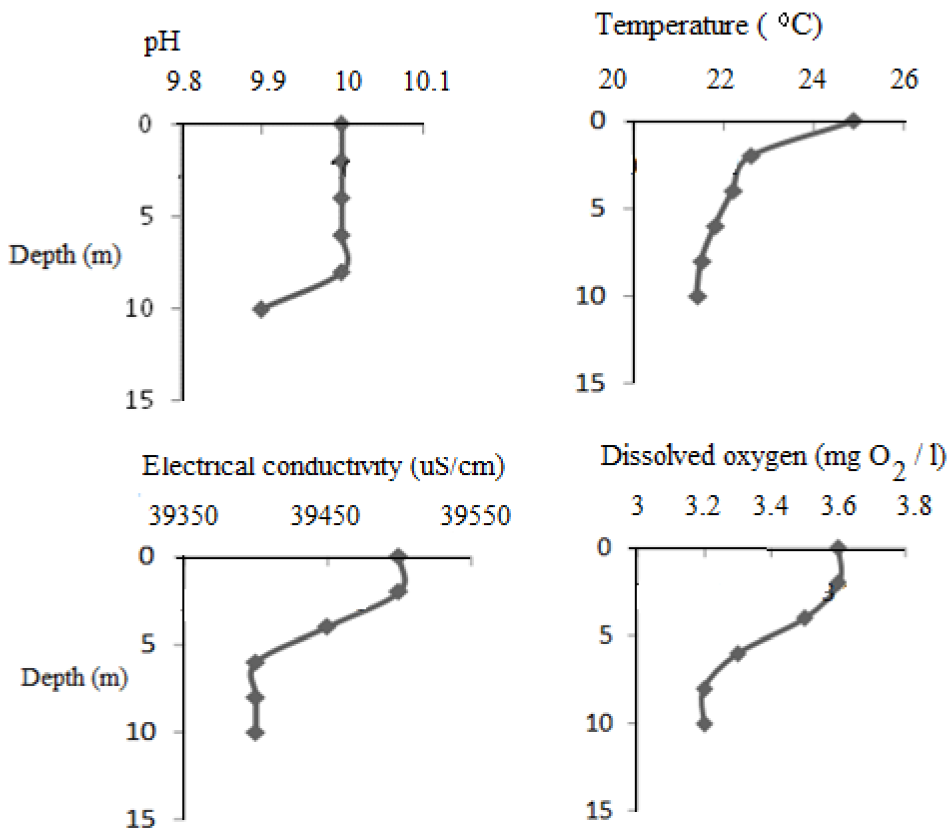



**Figure 3.4:** Changes of various water parameters with water depth in Lake Big Momella in November, 2013.

Vertical variations were also observed in March, 2014. With the exception of pH which remained constant down the water column up to a depth of 8 meters. All the other parameters showed variations with water depth. Water temperature decreased from 27.9 to 23.9 $^{0}$C, electrical conductivity from 40200µS/cm to 39700µS/cm and dissolved oxygen from 16.4 mg/l to 3.9 mg/l as illustrated in figure 3.5.

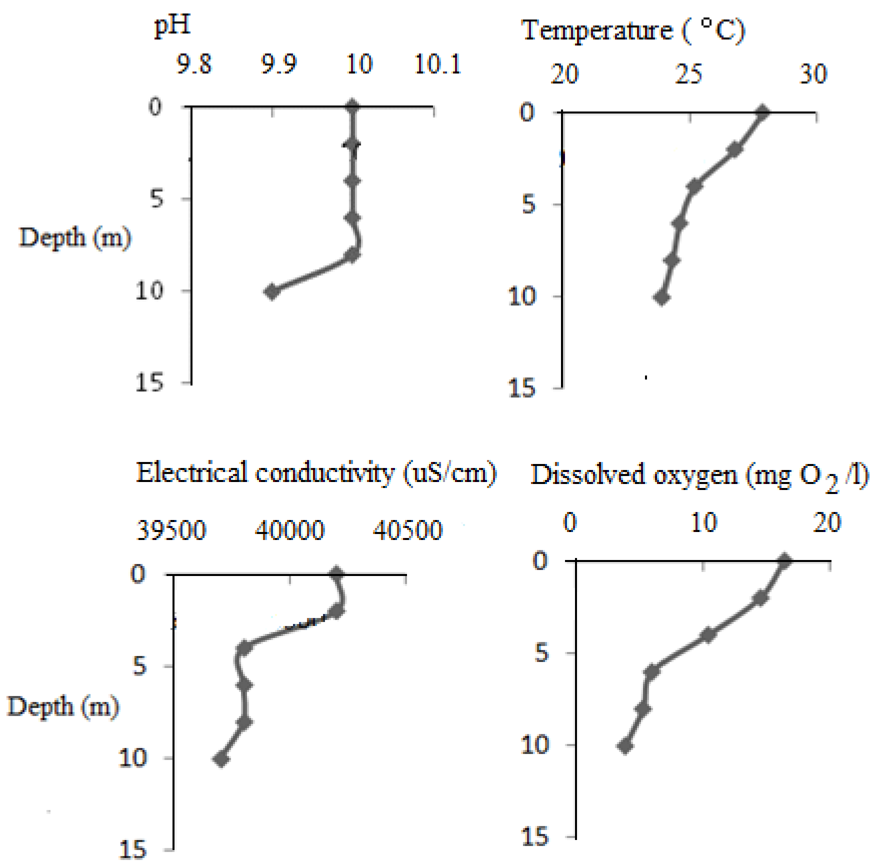



**Figure 3.5:** Changes of various water parameters with water depth in Lake Big Momella in March, 2014

### 3.1.3.2 Lake Rishateni

Water pH at Lake Rishateni like in Lake Big Momella did not show any major changes with water depth as observed in November, 2013. All the other selected parameters decreased in values down the water column. It was observed that water temperature decreased from 22.2 to 19.2 $^{0}$C, electrical conductivity from 29,700 to 29,600µS/cm and dissolved oxygen from 3.7 to 2.8 mg/l as shown in figure 3.6.

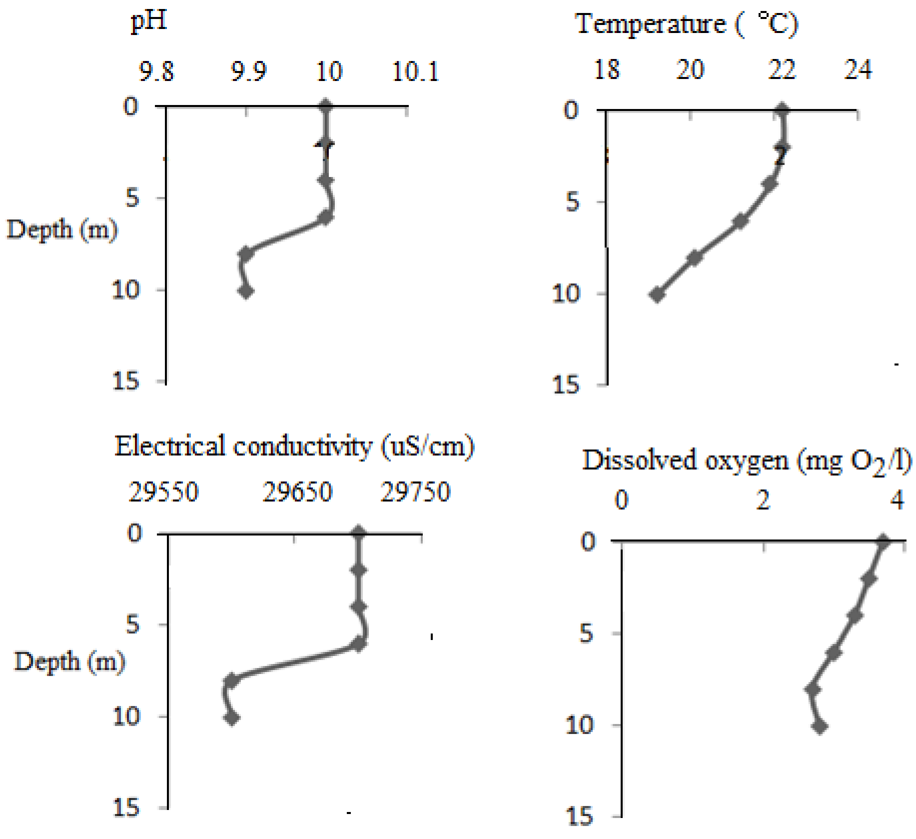



**Figure 3.6:** Changes of various water parameters with water depth in Lake Rishateni in November, 2014.

On the other electrical conductivity behaved in a different manner in March, 2014 as it increased with depth from 29500 to 30300 µS/cm. All the selected parameters except pH showed a decrease in values down the water column. Water temperature decreased down the water column from 28.3 to 24.6 $^{0}$C and dissolved oxygen from 17.2 to 4.1 mg/l as shown in figure 3.7

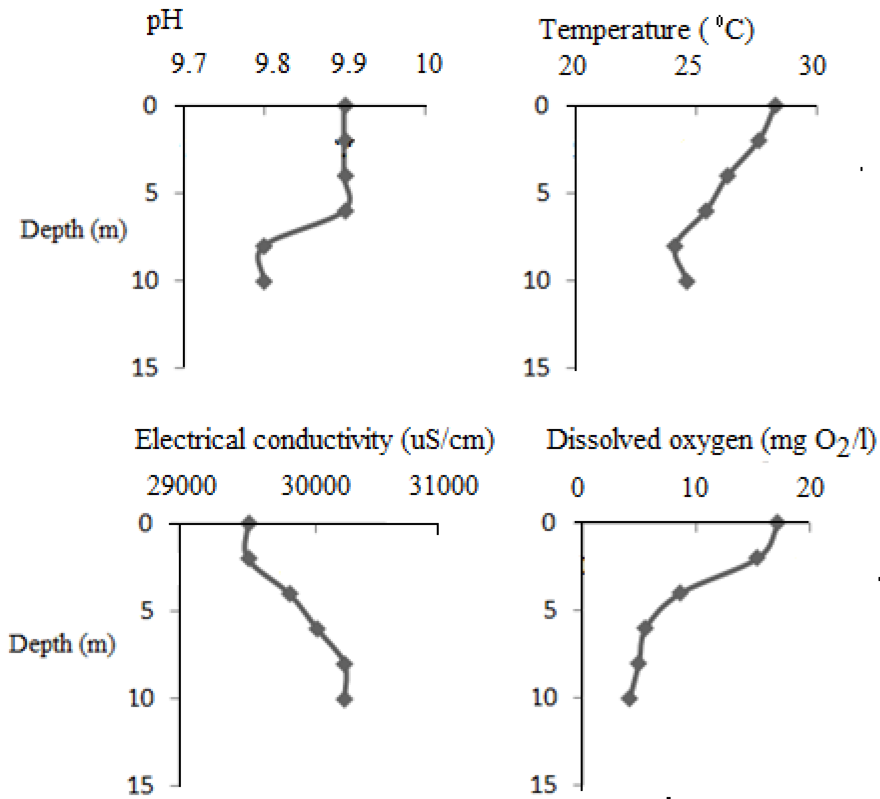



**Figure 3.7:** Changes of various water parameters with water depth in Lake Rishateni in March, 2014.

### 3.1.4 Chemical parameters

#### 3.1.4.1 Total phosphorus

The general trend showed that the concentration of phosphorus from November, 2013 to February, 2014 was relatively low in Lake Big Momella compared to the rest of the months of March, April and May, 2014. The highest and lowest concentrations of phosphorus were 2.63 mg/l and 0.08 mg/l recorded in April, 2014 and November, 2013 respectively. On the other hand the trend of phosphorus concentration in Lake Rishateni was observed to be similar to that of Lake Big Momella. From November, 2013 to February, 2014 phosphorus concentration was relatively low compared to the following months of March, April and May, 2014. Unlike Lake Big Momella the highest and lowest concentrations of phosphorus in Lake Rishateni were 1.75 mg/l and 0.05 mg/l recorded in March, 2014 and in November, 2013 respectively. However, the concentration of total phosphorus in March and April, 2014 was higher in Lake Big Momella than in Lake Rishateni as shown in figure 3.8.

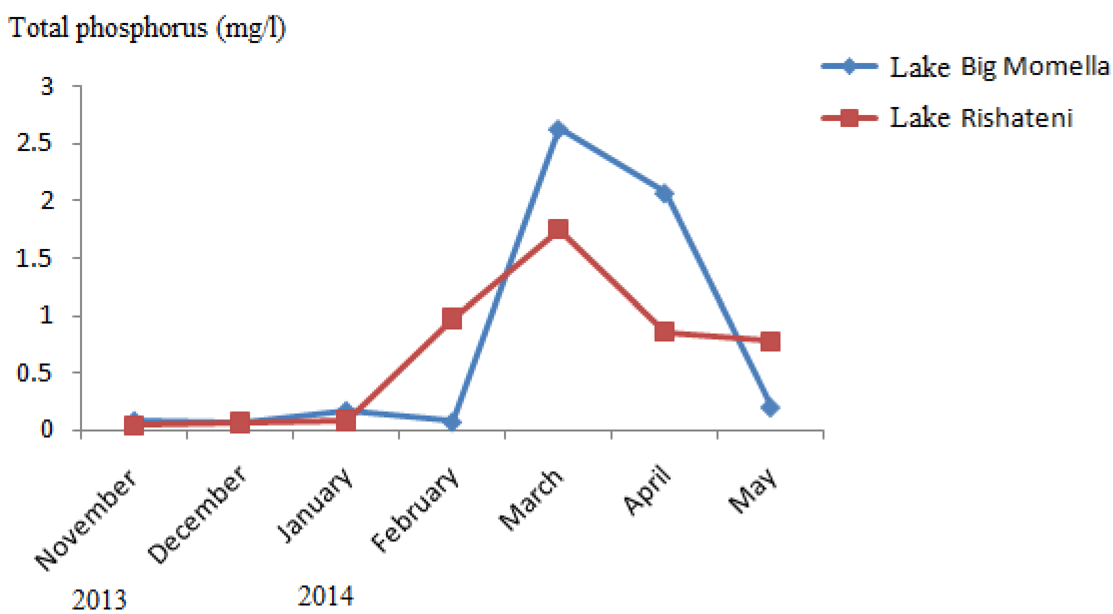



**Figure 3.8:** Monthly changes in phosphorus concentration in Lake Big Momella and Lake Rishateni from November, 2013 to May, 2014.

### 3.1.4.2 Total nitrogen

With respect to nitrogen, the trend shows that concentration was relatively low in Lake Big Momella during the first two months of this study (November and December, 2013) and thereafter a gradual increase was noted in the remaining months of January, February, March, April and May, 2014. The lowest and highest concentrations of nitrogen were 2.9 mg/l and 38.4 mg/l recorded in November, 2013 and April, 2014. On the other hand the lowest and highest concentrations of nitrogen in Lake Rishateni were 1.9 mg/l and 9.3 mg/l recorded in November, 2013 and May, 2014 respectively. The general trend in nitrogen concentration in Lake Rishateni just as it was in Lake Big Momella was relatively low in the first two months (November and December, 2013) and thereafter a gradual increase was noted in the remaining months of January, February, March, April and May, 2014. Unlike phosphorus the concentration of nitrogen was noted to be higher in Lake Big Momella than Lake Rishateni during the whole study period as shown in figure 3.9.

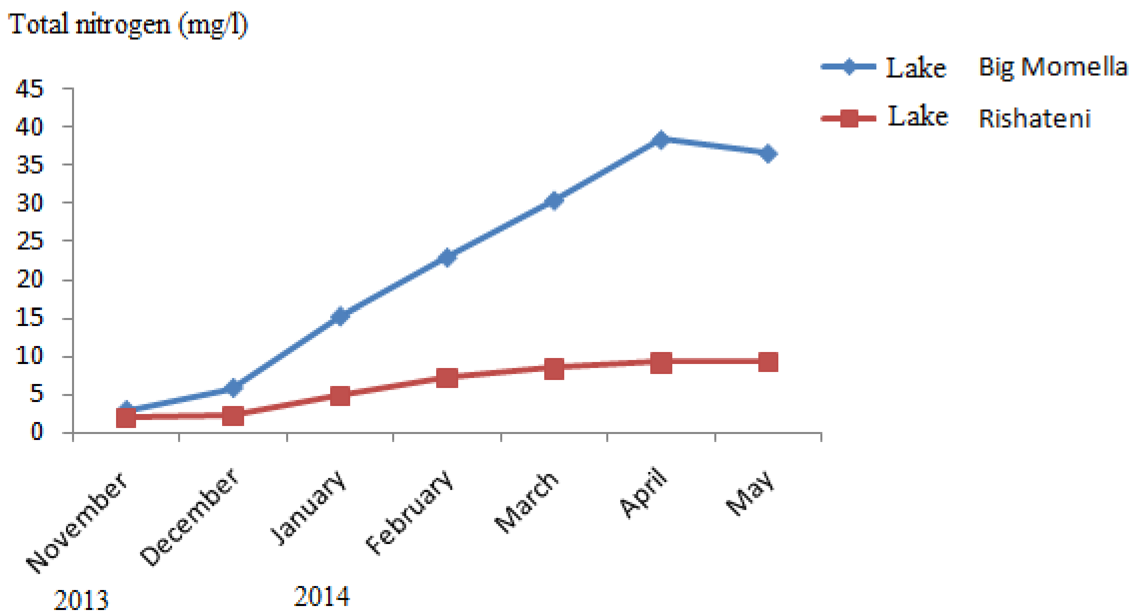



**Figure 3.9:** Monthly changes in nitrogen concentration in Lake Big Momella and Lake Rishateni from November, 2013 to May, 2014.

### 3.2 Comparison of the mean values (± SE) of physicochemical parameters

Comparison of the mean values of physicochemical parameters in Lake Big Momella and Lake Rishateni revealed that electrical conductivity (38954.09 ± 988.5 µS/cm), salinity (25.87 ± 0.21 ppt) and total nitrogen (21.74 ± 5.40 mg/l) were relatively higher in Lake Big Momella than in Lake Rishateni where the means for electrical conductivity, salinity and total nitrogen were found to be

29955.43 ± 1168.18 µS/cm, 18.77 ± 0.19 ppt and 6.14 ± 1.20 mg/l respectively. The mean values for all the other parameters did not show much difference. On the other hand a statistical comparison of the two lakes with regard to the physicochemical parameters revealed that there was a statistically significant difference in the water electrical conductivity, salinity and total nitrogen as inferred from One Way ANOVA ($F_{1, 13} = 34.578$, $p < 0.005$, $F_{1, 13} = 617.522$, $p < 0.005$ and $F_{1, 13} = 5.975$, $p < 0.031$ respectively). All the other parameters showed no significant difference as shown in table 3.1

**Table 3.1:** Comparison of mean values (±SE) of physicochemical parameters in Lake Big Momella and Lake Rishateni (NS =Not significant, S =Significant difference, $p < 0.05$).

| **Parameter** | **Big Momella** | **Rishateni** | **ANOVA** | | **Sig. D** |
|---|---|---|---|---|---|
| | **Mean (± SE)** | **Mean (± SE)** | $\mathbf{F_{1, 13}}$ | ***p* values** | |
| ***pH*** | 9.96 ± 0.02 | 9.97 ± 0.02 | = 0.273 | = 0.611 | NS |
| ***Temperature ($^0C$)*** | 25.42 ± 0.65 | 26.30 ± 0.50 | = 1.610 | = 0.303 | NS |
| ***E. C (µS/cm)*** | 38954.09 ± 988.5 | 29955.43 ± 1168.18 | = 34.578 | = 0.005 | S |
| ***D.O (mg $O_2$/l)*** | 14.04 ± 0.83 | 12.73 ± 2.32 | = 0.284 | = 0.604 | NS |
| ***Light Transparency (cm)*** | 36.17 ± 1.60 | 33.33 ± 2.38 | = 1.098 | = 0.315 | NS |
| ***Salinity (ppt)*** | 25.87 ± 0.21 | 18.77 ± 0.19 | = 617.522 | = 0.005 | S |
| ***Total Nitrogen (mg/l)*** | 21.74 ± 5.40 | 6.14 ± 1.20 | = 5.975 | = 0.031 | S |
| ***Total Phosphorus (mg/l)*** | 0.75 ± 0.42 | 0.65 ± 0.24 | = 0.094 | = 0.765 | NS |

### 3.3 Influence of physicochemical parameters on algal biomass

Statistically it was observed that in Lake Big Momella water pH (9.96) and salinity (25.87 ppt) showed no significant correlation with mean algal biomass (7.28 µg/l). All the other parameters which included water temperature (25.4 $^{0}$C), electrical conductivity (38,954 µS/cm), dissolved oxygen (14.04 mg/l), light transparency (36.17 cm), total nitrogen (21.74 mg/l) and total phosphorus (0.75 mg/l) showed a significantly positive correlation with mean algal biomass as inferred from Pearson's r correlation coefficients. The phenomenon observed in Lake Big Momella was also observed in Lake Rishateni. That is with the exception of water salinity (18.78 ppt) and pH (9.97) which showed no significant correlation with mean algal biomass (7.74 mg/l). All the other parameters, which included water temperature (26.3$^{0}$C), electrical conductivity (29955.4 µS/cm), dissolved oxygen (12.73 mg/l), light transparency (33.33 cm), total nitrogen (6.14 mg/l) and total phosphorus (0.65 mg/l) showed a positive significant correlation with mean algal biomass as shown in table 3.2

**Table 3.2:** Influence of physicochemical parameters on algal biomass algal biomass in Lake Big Momella and Lake Rishateni

| Parameter | Lake Big Momella | | Lake Rishateni | |
|---|---|---|---|---|
| | **r values** | ***p* *values*** | **r values** | ***p* values** |
| ***Temperature ($^{0}$C*** | = 0.956 | = 0.001 | = 0.927 | = 0.003 |
| ***E. C (µS/cm)*** | = 0.813 | = 0.026 | = 0.857 | = 0.014 |
| ***D.O (mg $O_2$/l)*** | = 0.921 | = 0.003 | = 0.921 | = 0.003 |
| ***Light transparency (cm)*** | = 0.882 | = 0.009 | = 0.951 | = 0.001 |
| ***Total nitrogen (mg/l)*** | = 0.944 | = 0.001 | = 0.916 | = 0.004 |
| ***Total phosphorus (mg/l)*** | = 0.803 | = 0.03 | = 0.865 | = 0.012 |

### 3.4 Algal biomass (µg/l)

There were variations in mean algal biomass during the study period in both lakes. In Lake Big Momella, for instance, mean algal biomass varied from 4.32µg/l to 9.86µg/l recorded in December, 2013 and April, 2014 respectively. In Lake Rishateni, the mean algal biomass varied from 4.86µg/l to 10.95µg/l in November, 2013 and April, 2014 respectively. The trend in mean algal biomass with regard to Lake Big Momella showed that there was a progressive increase in mean algal biomass from November, 2013 to April, 2014 and thereafter a decrease in mean algal was noted as illustrated in figure 3.10

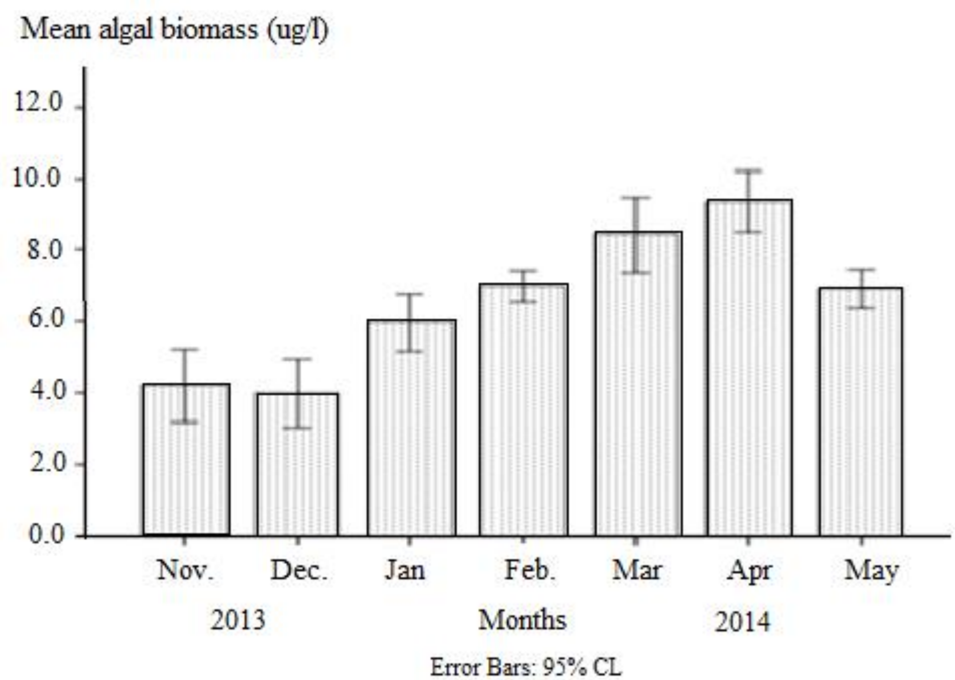



**Figure 3.10:** Monthly changes in mean algal biomass in Lake Big Momella during the study period from November, 2013 to May, 2014

The trend observed in Lake Big Momella with regard to mean algal abundance during the period of this study was also observed in Lake Rishateni. That is with the exception of December, 2013 when there was a progressive increase in mean algal abundance from November, 2013 to April, 2014. Thereafter a decrease in mean algal abundance in Lake Rishateni was observed in May, 2014 as shown in figure 3.11

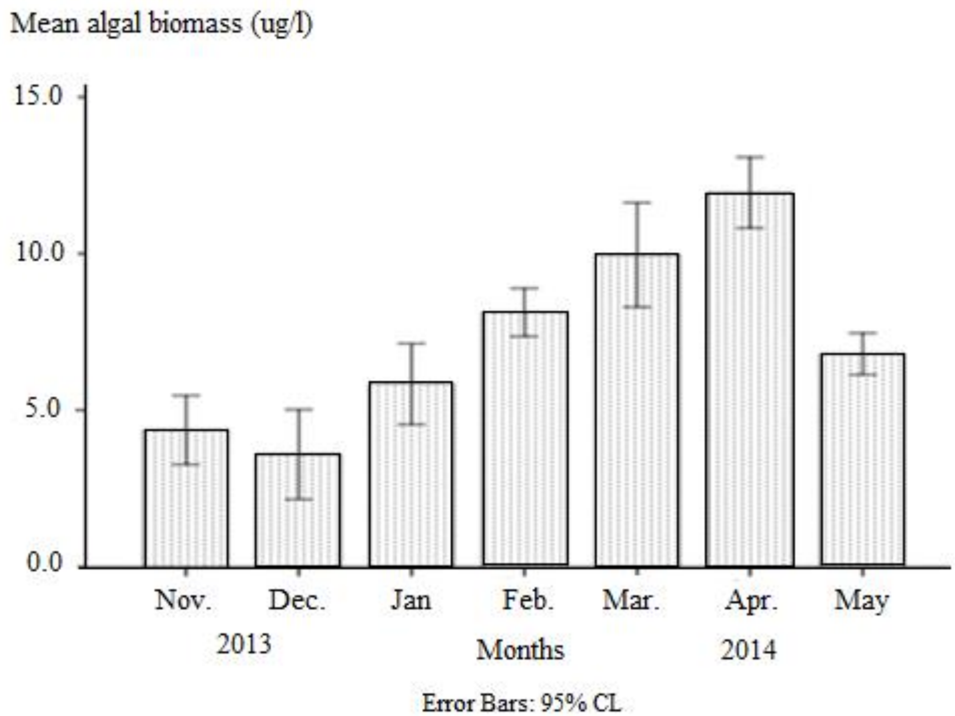



**Figure 3.11:** Monthly changes in mean algal biomass in Lake Rishateni during the study period from November, 2013 to May, 2014

## 3.5 Comparison of algal biomass between lakes Big Momella and Rishateni

Comparison of mean algal biomass in lakes Big Momella and Rishateni by sampling sites showed that there was no significant difference in mean algal biomass between the sampling sites in Lake Big Momella and Lake Rishateni as inferred from One Way ANOVA ($F_{2, 57} = 0.545$, $p = 0.583$ and $F_{2, 57} = 0.285$, $p = 0.753$ respectively). On the other hand a statistically significant difference in mean algal biomass between seasons was observed between Lake Big Momella and Lake

Rishateni as inferred again from Two Way ANOVA ($F_{1,3,\ 58}$ = 27.576, p = 0.0005 and $F_{(1,3,\ 58)}$ = 17.344, p = 0.0005 respectively). The dry season which was marked by the months from November, 2013 to February, 2014, the lowest mean algal biomass in Lake Rishateni was 4.86µg/l recorded, while that of Lake Big Momella was 4.0µg/l recorded in November and December, 2013 respectively. On the other hand during the wet season which included the period from March to May, 2014 the highest mean biomass of 9.35µg/l and 10.5µg/l were recorded in April, 2014 in Lakes Big Momella and Rishateni respectively.

### 3.6 Algae species identification

Microscopic observation of the scum and water samples taken from the lakes during the study period revealed the presence of diatoms and a variety of algae species of which some formed part of the common diet for the lesser flamingo e.g. *A. fusiformis*. Other harmful algal species to the survival of the lesser flamingos e.g. *Microcystis* and *Anabana spp.* were also identified as shown in plate 3.1

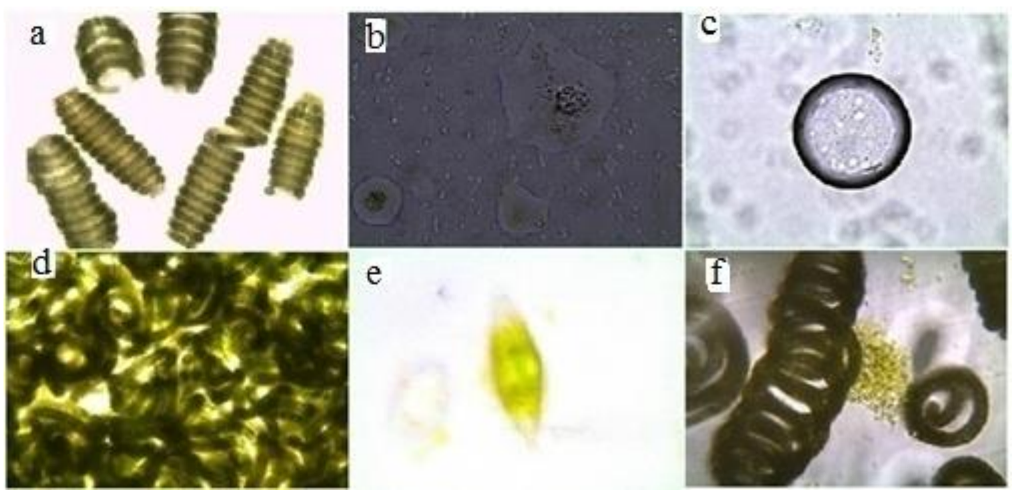


**Plate 3.1:** **a** = *A. fusiformis* (x 200), **b** = *Microcystis spp*. (x 400), **c** = *Anabaena spp*. (x 400) **d** = Algal bloom (*A. fusiformis*) (x 200), **e** = Diatom (*C. Ehrenbergii*) (x 400), **f** = *A. fusiformis* mixed with *Microcystis spp.* (x400).

The counting of species under x400 magnification revealed that in Lake Big Momella *A. fusiformis* ranged from 1 to 8 individuals, *Microcystis* from 1 to 4 individuals while *Anabaenopsis* and diatoms ranged from 1 to 2 individuals per field of view with a diversity index of 0.8568. In Lake Rishateni *A. fusiformis* ranged from 1 to 9 individuals, *Microcystis* like in Lake Big Momella ranged from 1 to 4 individuals, *Anabaenopsis* and diatoms ranged from 1 to 2 individuals per field of view with a diversity index of 0.9460 as illustrated in Tables 3.3 and 3.4 respectively.

**Table 3:3** Monthly groups and counts of algae species identified in Lake Bid Momella from November, 2013 to May, 2014 (**H′=** Shannon Wiener Diversity Index)

| **Months** | **Algae species (individuals / field of view of x400)** | | | | | **H′** |
|---|---|---|---|---|---|---|
| | *A. fusiformis* | *Microcystis* | *Anabaena spp.* | *Diatoms* | **Total** | |
| November | 5 | 1 | 1 | 0 | **7** | |
| December | 7 | 1 | 0 | 1 | **9** | |
| January | 5 | 1 | 0 | 1 | **7** | |
| February | 6 | 2 | 1 | 0 | **9** | |
| March | 8 | 4 | 0 | 0 | **12** | |
| April | 8 | 2 | 1 | 1 | **12** | |
| May | 7 | 0 | 1 | 0 | **8** | |
| **Total (*species i*)** | **46** | **11** | **4** | **3** | **64** | **0.8568** |

**Table 3.4:** Monthly groups and counts of algae species identified in Lake Rishateni from November, 2013 to May, 2014 (**H′=** Shannon Wiener Diversity Index)

| **Months** | **Algae species (individuals / field of view of x400)** | | | | | **H′** |
|---|---|---|---|---|---|---|
| | *A. fusiformis* | *Microcystis* | *Anabaena spp.* | *Diatoms* | **Total** | |
| November | 5 | 2 | 1 | 0 | **8** | |
| December | 5 | 2 | 2 | 1 | **10** | |
| January | 6 | 1 | 0 | 1 | **8** | |
| February | 8 | 1 | 1 | 0 | **10** | |
| March | 9 | 2 | 0 | 1 | **12** | |
| April | 9 | 4 | 1 | 0 | **14** | |
| May | 6 | 1 | 1 | 1 | **9** | |
| **Total (*species i*)** | **48** | **13** | **6** | **4** | **71** | **0.9460** |

Comparing the two lakes it was observed that the number of *A. fusiformis* was higher in all the observed slides in both lakes compared to other species being followed by *Microcystis*, *Anabaenopsis* and diatoms respectively during the study period from November, 2013 to May, 2014. Comparison with respect to algae species counts and algal biomass in lakes Big Momella and Rishateni revealed that the lowest total counts of the species per field of view were 7 and 8 recorded in November, 2013 and January, 2014 respectively. During this period the lowest mean algal biomass in lakes Big Momella and Rishateni were 4.32µg/l and 4.86µg/l recorded in November and December, 2013 respectively.

On the other hand the highest total counts of the species per field of view were 12 recorded in March and April, 2014 in Lake Big Momella and 14 recorded in March, 2014 in Lake Rishateni. While the highest mean algal biomass of 9.89µg/l and 10.95µg/l were recorded in April, 2014 in lakes Big Momella and Rishateni respectively. Generally Lake Rishateni was observed to have higher level of the total counts of the species as well as mean algal biomass during the study period from November, 2013 to May, 2014.

### 3.7 Lesser flamingo counts

The trend in lesser flamingo counts generally showed that there was a rapid decrease in the total number of birds in both lakes during the study period. At Lake Big Momella the highest and the lowest numbers were 43,914 and 306 recorded in November, 2013 and May, 2014 respectively. At Lake Rishateni the highest number was 12,495 recorded in November, 2013 and the lowest number was 0 recorded in the last three months of this study that is March, April and May, 2014. Comparatively Lake Big Momella accommodated a larger total number of lesser flamingos than Lake Rishateni in all the months during which this study was conducted as illustrated in figure 3.12.

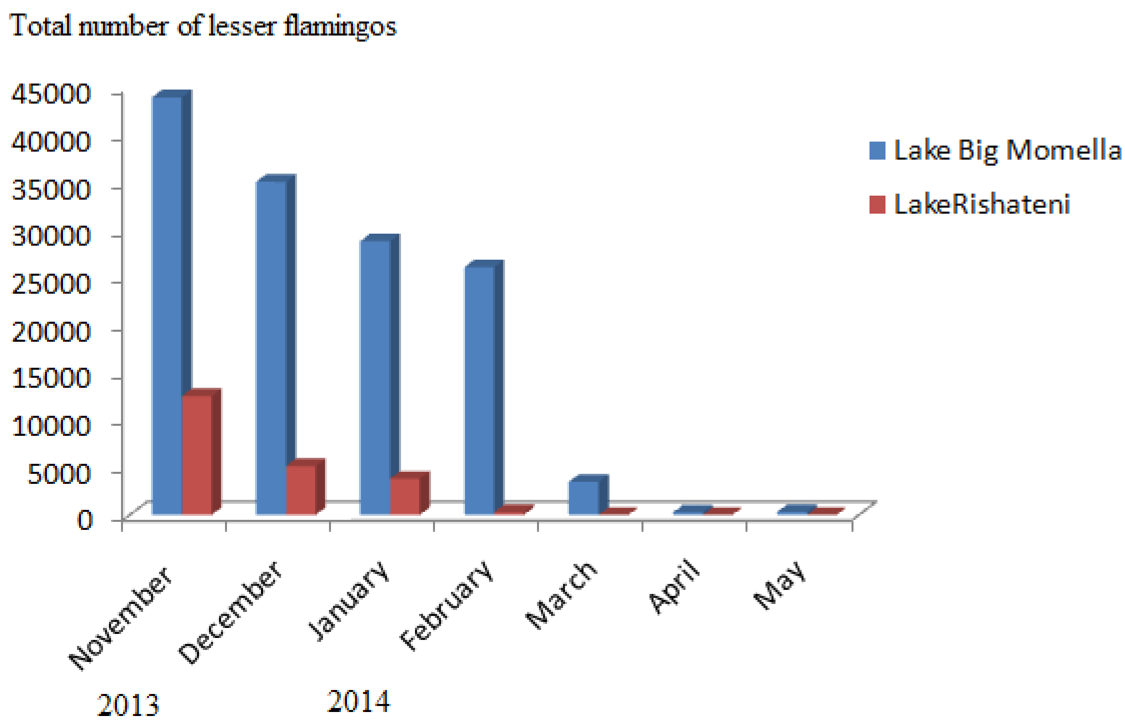



**Figure 3.12:** Temporal variations in lesser flamingos in lakes Big Momella and Rishateni during the study period from November, 2013 to May, 2014

Despite the fact that in November, 2013 there were high numbers of lesser flamingos in both lakes, departures was also high. On the 29$^{th}$ November, 2013 over 300 flamingo carcasses were collected by the park rangers from Lake Big Momella and 22 flamingo carcasses were recorded in Lake Rishateni. It was explained by Mr. Mutobha (one of the Park officials) that death rate in November, 2013 went to about 600 flamingos per day in some days. On the other hand as the number of total lesser flamingos decreased, the die offs also decreased.

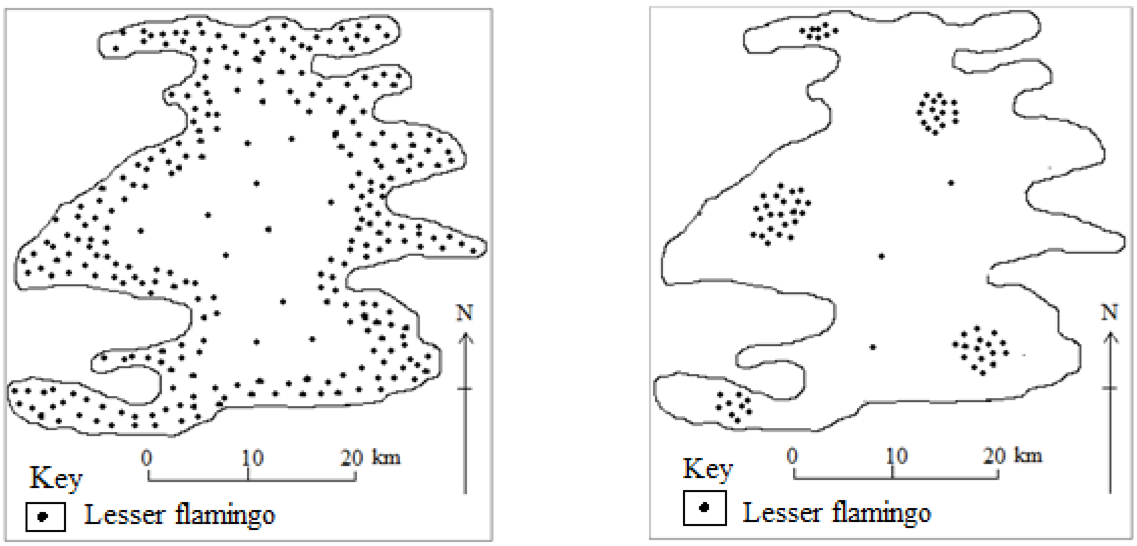
### 3.8 Algal biomass and temporal variation in lesser flamingo counts

The findings indicated that the influence of algal biomass on temporal variation of the number of lesser flamingo populations was statistically significant in both lakes. In Lake Big Momella, the

Pearson's r for the correlation between algal biomass and the temporal fluctuation of lesser flamingos was statistically significant ($r = -0.876$, $p < 0.05$). This indicated that there was a strong negative correlation between these two variables. That is as algal biomass was increasing total number of lesser flamingo population was decreasing in the lake. Therefore, coefficient of determination ($r^2$) was 0.767, indicating that 77% of the fluctuations in the number of lesser flamingos in the Lake Big Momella could be explained by variability in algal biomass. A statistically significant negative relationship between algal biomass and lesser flamingo population was likewise noted in Lake Rishateni, where the Pearson's r for the correlation between algal biomass and the temporal fluctuation of lesser flamingos was also statistically significant ($r = -0.942$, $p < 0.05$). This again indicated that there was also a strong negative correlation between these two variables whereby as algal biomass was increasing, while the total number of lesser flamingo population was decreasing in the lake. Therefore, coefficient of determination ($r^2$) was 0.88 indicating that 88% of the fluctuations in the total number of lesser flamingos could be explained by variations in algal biomass

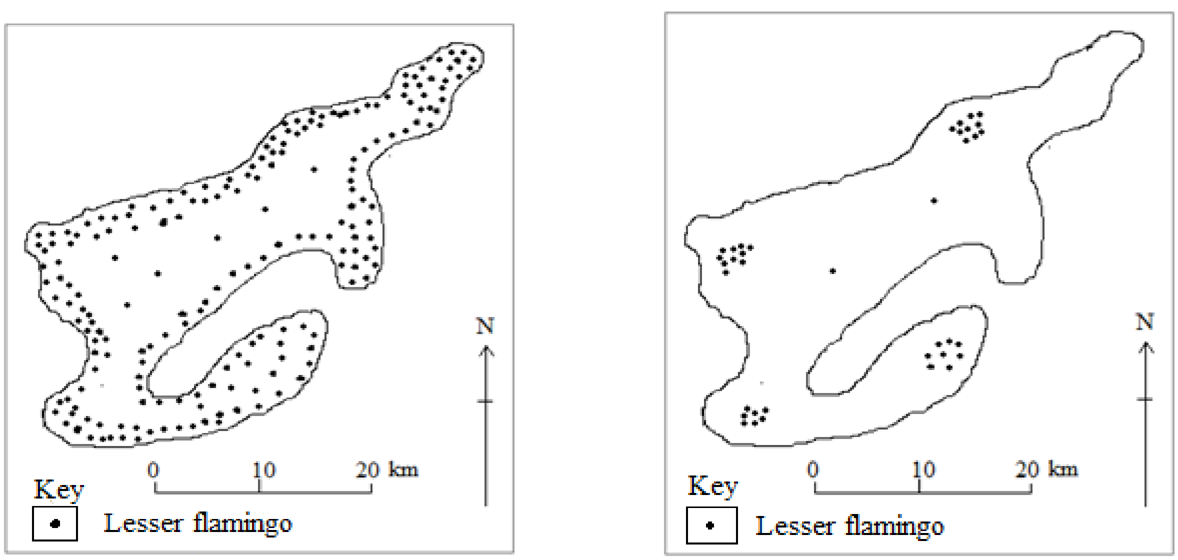
### 3.9 Distribution patterns of lesser flamingos in the lakes.

The spatial distribution lesser flamingo showed that the birds were widely dispersed in both lakes during the first four months of the study from November, 2013 to February, 2014. During this period lesser flamingos utilized mostly the inshore areas and a few of them utilized the offshore areas for feeding resting, roosting, bathing and performing courtship displays. However, the rapid decrease in total number of lesser flamingo population was accompanied with a change in their spatial pattern of distribution. The change in distribution pattern from being widely dispersed to forming clusters was observed in February, 2014 when scum and algal blooms covered large surface area in the lakes. The change in distribution pattern of lesser flamingos in lakes Big Momella and Rishateni as a result of scum and algal blooms is illustrated in figure 3.13




November, 2013 February, 2014

**Figure 3.13:** Distribution pattern of lesser flamingos in Lake Big Momella as observed in November, 2013 and March, 2014.




November, 2013 February, 2014

**Figure 3:14:** Distribution pattern of lesser flamingos in Lake Rishateni as observed on the 29th November, 2013 and February, 2014.

The clumped distribution pattern was accelerated by the presence of scum of blue green algae that covered the surface of the waters especially in some parts of the shores as illustrated in Plate 3.2

**Plate 3.2:** Scum covering one of the shores in lake Big Momella (3rd February, 2014).

## 3.10 Lake morphometrics and lesser flamingo fluctuations

### 3.10.1 Lake Big Momella

In lake Big Momella the Pearson's r for the correlation between water depth changes and total number of lesser flamingos was statistically significant ($r = -0.859$, $p = 0.006$). This suggested that there was a strong negative correlation between the two variables. It was observed that when the lowest average water depth was 8.5 meters recorded during the dry season in November, 2013, the corresponding number of lesser flamingos was 43,914. On the other hand when the highest average water depths was 10.5 meters recorded during the wet season in April, 2014, the corresponding number of lesser flamingos was 258. The trend by which water depth and lesser flamingo counts were related in Lake Big Momella is shown in figure 3.15.

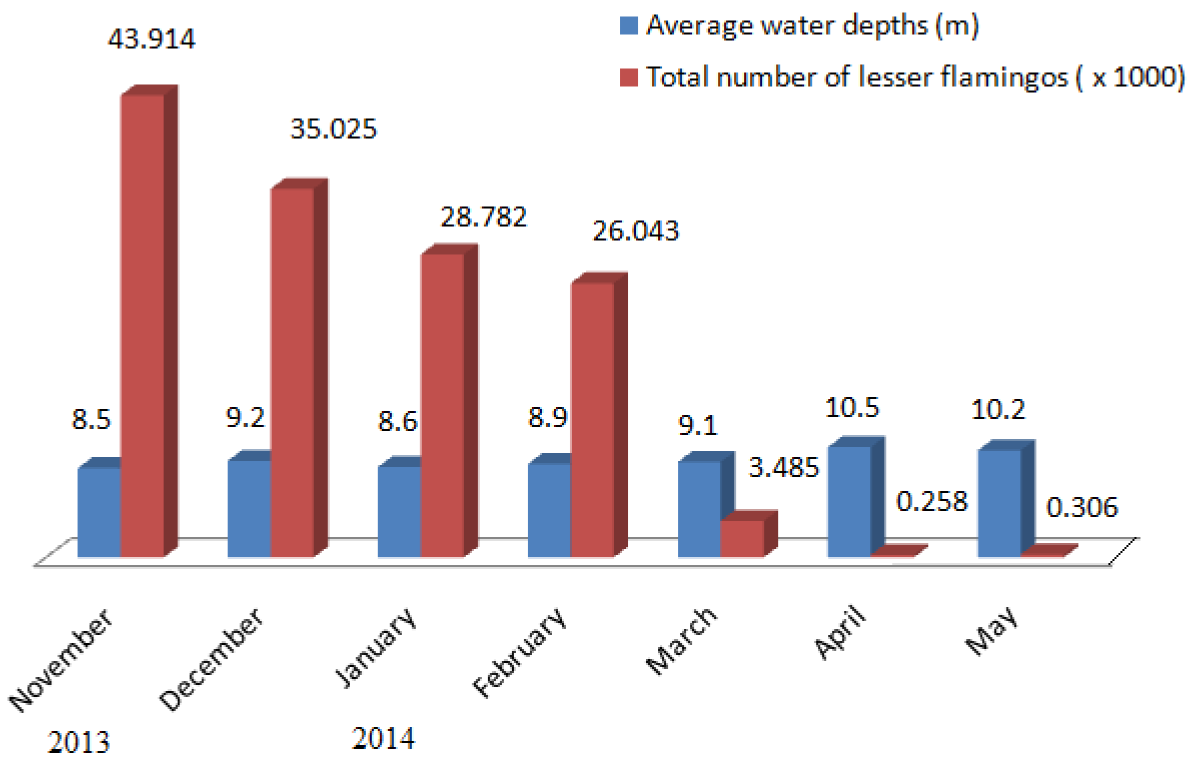



**Figure 3.15:** The trend by which water depth and lesser flamingo counts were related in Lake Big Momella from November, 2013 to May, 2014.

### 3.10.2 Lake Rishateni

In lake Rishateni a similar phenomenon was observed that is there was also a high negative correlation between shoreline water depth changes and total lesser flamingo population as again suggested by Pearson's r correlation value ($r = -0.875$, $p = 0.004$). Like in Lake Big Momella it was also noted that when the lowest average water depth was 7.9 meters recorded during the dry season in November, 2013 with respect to the sampling sites the corresponding number of lesser flamingos was 12,495. And when the highest average water depths was 10.2 meters recorded during the wet season in April, 2014 the corresponding number of lesser flamingo was 0. The trend showing the relationship between water depth and lesser flamingo counts were related in Lake Rishateni is shown in figure 3.16.

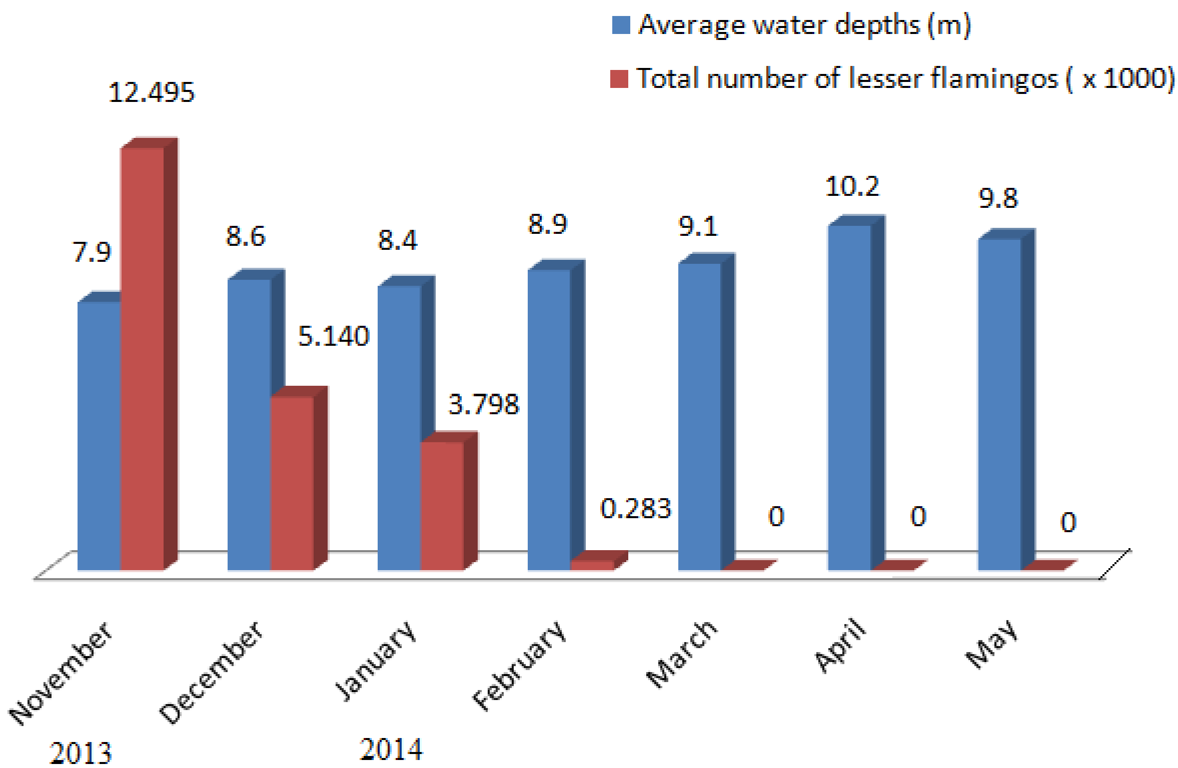



**Figure 3.16:** The trend by which water depth and lesser flamingo counts were related in Lake Rishateni from November, 2013 to May, 2014

It was also observed in both lakes that water fluctuations resulted into water flooding in some of the shores and shallow areas that were critical for utilization by lesser flamingos. In Lake Big Momella for instance such areas were explained by Mr. Sabato Mutobha (one of the Park Officials) to be of high utilization by lesser flamingos for resting, roosting and display of courtship dances especially in months of September, October, November and December, .

Increase in shoreline water levels due to increased rainfalls especially in April, 2014 resulted into water flooding in the exposed areas along the shores in the lakes as shown in Plate 3.3

November, 2013 April, 2014

**Plate 3.3:** One of the exposed shores with scattered water pools and flamingos in Lake Big Momella as observed in November, 2013 and April, 2014.

# CHAPTER FOUR

# DISCUSSION

This study was intended to establish the relationship of the factors that influence food availability and habitat utilization of lesser flamingos *Phoeniconaias minor* (Geoffroy, 1798) following their frequent deaths and general population decline in the Momella lakes ecosystem. The factors included water quality, algal biomass and lake morphometry (water depth). Thus it explored the physicochemical parameters that affect water quality and algal biomass and on how algal biomass and lake morphometry (water depth) were related to the numbers of lesser flamingos utilizing Lake Big Momella and Lake Rishateni in Arusha National Park, Tanzania.

## 4.1 Physicochemical parameters and shifts in algal biomass

The findings of this study revealed that there were significant differences between the physicochemical parameters which in turn accelerated not only shifts in algal biomass, but also proliferation algal blooms in the study lakes. Changes in physicochemical characteristics were manifested in variations in algal biomass, which was also associated with the negative temporal fluctuations in lesser flamingos inhabiting the lakes studied in Arusha National Park, Tanzania. This observation concurs with the previous investigation by Kihwele, Lugomela & Howell, (2014) that changes in physicochemical parameters are always associated with shifts in algae composition and dominance. These changes in turn influence lesser flamingo food, numbers and distribution in such lake ecosystems.

Nutrient enrichment has also been observed in this study to promote not only shifts in algal biomass but also proliferation of algal blooms creating unfavorable feeding conditions for the lesser flamingos in the study lakes. It was revealed in the findings of this study that total phosphorus and total nitrogen concentrations had a significant positive correlation with algal biomass. This indicated that phosphorus and nitrogen were among the driving factors that accelerated the increase in algal biomass and proliferation of algal blooms especially in April, 2014 due to high levels of nutrients following the heavy rains during the season.

This is observation is in agreement with the previous studies done by Purves *et al.,* (2003) and Rast *et al*., (1989). They showed that high levels of nutrients particularly phosphorus and nitrogen in combination with other factors such as sufficient light and high temperature provided favorable conditions for high primary production in most aquatic ecosystems. The increase in algal biomass as well as the appearance of algal blooms as a result of nutrient increase in the lakes as observed in this study again concurs with the previous studies done by Harper, (1992) in Lake Naivasha. He observed that when nutrients particularly nitrogen and phosphorus are increased, eutrophication within the system also increases and primary production is accelerated as well. Nutrient enrichment particularly phosphorus and nitrogen as already investigated by Githaiga, (2003) has been explained often to play a significant role in determining primary production and species composition in many aquatic ecosystems. The blooms observed in Lake Big Momella and Lake Rishateni reduced water quality and contaminated the food of the lesser flamingos in the lakes.

The sources of the high level of nutrients in Lakes Big Momella and Lake Rishateni could be due to anthropogenic activities like agriculture and animal keeping that are done in the catchment areas on the north eastern part of the Momella lakes ecosystem. This implies that during heavy rains runoffs from the catchment areas can bring in nutrients from the fields and settlements. This fact is also supported by previous investigations such as those by Mwaura and Moore, (1991). They observed that high levels of nutrients in such aquatic ecosystems could be due to inappropriate agricultural practices as a result of increased human settlement that leads to an increase in soil erosion and nutrient loads in the catchment areas of the lakes. On the other hand, lesser flamingos and other water bird species could be another source of nutrients especially nitrogen through their fecal materials. It was observed in this study that Lake Big Momella and Lake Rishateni supported large numbers of lesser flamingos especially in November and December, 2013 that might have contributed to nutrient enrichment through their fecal materials. This is also supported by previous studies done by Kihwele, Lugomela & Howell, (2014) in Lake Manyara. They observed that the relatively high levels of nitrogen than phosphorus during the study period was due to the presence of high numbers of the lesser flamingos and other water birds as their droppings into water contributed to the nutrient enrichment.

In addition, Lake Big Momella and Lake Rishateni do not have outlets that could allow some of the nutrients to flow out of the lakes. The lack of outlets especially when there is a low (below 29) TN: TP ratio could also be another reason for the resulting accumulation of nutrients in the lakes favoring cyanobacterial blooms and dominance as already documented in the findings such as those by Smith, (1983). Consequently, the appearance of algal blooms in such aquatic ecosystems is in most cases a clear sign of high levels of eutrophication. This is in agreement with the investigations done by Mwaura *et al.*, (2004) in Lake Bogoria revealed that eutrophication normally stimulates excessive growth of algae in a phenomenon referred to as ‘algal blooming’. He observed that during blooms, phytoplankton composition is narrowed by the dominance of cyanobacteria while the biomass is usually very close to carrying capacity and insufficient light and nutrient supply temporarily limit any further growth.

Cyanobacterial blooms and mats are increasingly recognized worldwide as sources of potent cyanotoxins in most aquatic ecosystems according to studies done by Codd *et al*., (1999). The prolific growth of certain algae, particularly the blue-greens algae, is also known to release toxins such as hepatotoxins and lipopolysacharide endotoxins in the water that consequently affected the feeding ecology and utilization patterns of lesser flamingos in the lakes (Annadotter *et al.* 1999, Harper 1992). The high levels of nitrogen and phosphorus concentration pose a danger to the quality of the water for the survival of lesser flamingos and other organisms that inhabit the Momella lakes ecosystem. This is because nitrogen and phosphorus are the key nutrients that normally accelerate the growth of algae in many water bodies. According to William, (1999) phosphorus is not only a limiting factor for the growth of phytoplankton but also for the proliferation of algal blooms in many water bodies. Its abundances however, reduce water quality, alter species composition and produces bad odor.

Therefore, changes in physicochemical parameters and nutrient enrichment particularly phosphorus and nitrogen resulted into shifts in algal biomass as inferred from the findings of this study. Shifts in algal biomass and proliferation of algal blooms could be one of the reasons that affected the quality of food, temporal distribution and availability of lesser flamingos in the Momella lakes ecosystem.

## 4.2 Algae species diversity and abundance

This was an important aspect considered in finding out the factors that affected the food and utilization of the lakes by lesser flamingos. The identification process of microalgae as observed in this study indicated the presence of not only the food species (*A. fusiformis*) but also other algal species (*Microcystis* and *Anabaenopsis*) in Lake Big Momella and Rishateni. These two species gave more confirmation that there might be a problem with the quality of food for the lesser flamingos in the lakes. This is because the blue green algae in the lakes was composed of not only the common diet *A. fusiformis*, but also other algal species like the *Microcystis* and *Anabaenopsis* that are harmful to the lesser flamingos and could have contributed to the die offs observed.

This fact concurs with the reports of previous investigations such as those by Krienitz and Kotut, (2010) in Lake Bogoria that the blue green algae are composed of not only the preferred food for the lesser flamingos, but also other harmful species like the *Anabaenopsis*. The findings revealed that during July 2008 two-thirds of the phytoplankton biomass in Lake Bogoria was observed to comprise *Anabaenopsis spp.* Coincidentally, the deaths of about 30,000 lesser flamingos occurred at the same time with the mass development of *Anabaenopsis.* Consequently, the authors concluded that the *Anabaenopsis spp.* is too large to be ingested by the lesser flamingo, resulting in starvation. This might have contributed to the mass die-offs of flamingos observed in Lake Bogoria in July 2008. In addition apart from the toxins that they produce, *Anabaenopsis spp*. has also the potential to block and clog filtration system of the lesser flamingos as they normally exist in large and slimy colonies (Codd *et al*., 1999).

The presence of such harmful algal species e.g. *Microcystis* and *Anabaenopsis* could as well be one of the reasons for the die offs observed, changes in spatial distribution and temporal fluctuations in the number of lesser flamingo populations utilizing the Momella lakes ecosystem. This is because lesser flamingos being very sensitive to food quality and quantity, such food contaminants as already documented by Tuite (1978) could easily make them be affected by the contaminated food or shift to other saline lakes.

## 4.3 Algal biomass and temporal fluctuations of lesser flamingos

The ultimate impacts of the changes in the physicochemical composition of water were manifested in the shifts of biomass of the phytoplankton (food for the lesser flamingos) which was associated with decrease in flamingo numbers. It was observed in Lake Big Momella and Lake Rishateni that total number of lesser flamingos increased with an increase in algal biomass forming a positive linear relationship between these two variables up to a certain extent. However, as time went on the findings revealed that total number of lesser flamingos in the lakes continued to decrease gradually. The fact that numbers of lesser flamingos decreased with the increase in algal biomass as significantly observed during the study period indicated that something must be wrong with the quality of the preferred food for the lesser flamingos in the lakes.

At the beginning of this study in November, 2013 large numbers of lesser flamingo populations were seen utilizing both lakes. About 43,914 and 12,495 were counted in Lake Big Momella and Lake Rishateni respectively according to the counts done in November, 2013. According to Vareschi & Tuite (1978) the presence of such large numbers in such situation indicated that for the past one or two months before the commencement of this study the lakes had favorable conditions for the lesser flamingos including good water quality together with the presence of their common diet *A. fusiformis* and / or benthic diatoms. And the decrease in number of lesser flamingos implied that the food was already contaminated by other harmful algae species like the *Microcystis* and *Anabaenopsis* and this could be one among the factors towards the die offs observed, temporal fluctuations and decline in the number of lesser flamingos inhabiting the lakes. In addition when *A. fusiformis* biomass falls below a certain threshold, lesser flamingos are not able to obtain enough food to meet their energy requirements as already observed by Kaggwa *et al.,* (2013).

Consequently, lesser flamingos move to other saline lakes with a more favorable food base, alternatively they can even change their food to the less desirable phytoplankton species.

Although *A. fusiformis* as previously mentioned forms the main food and is regarded as non-toxic to the lesser flamingos recent findings by Ciferri, (1983) & Jassby, (1988) identified *A. fusiformis* as one source of microcystins and anatoxin-a in L. Bogoria and L. Nakuru. The findings detected microcystin-YR and anatoxin-*a* in cultured strain of *A. fusiformis* from Lake Bogoria and anatoxin-*a* was detected in a strain from Lake Nakuru. All these cyanotoxins have the potential to contaminate the food of the lesser flamingos and probably could also be one of the factors accounting for the decrease in numbers of lesser flamingo populations despite the fact that algal biomass was increasing in the Momella lakes ecosystems. Therefore, as *A.fusiformis* increases contamination with cyanotoxins increases, and hence the number of lesser flamingo die-offs increases sharply. The birds become weak and unable to fly away from the contaminated food.

With regard to spatial distribution it was observed at the beginning of this study in November, 2013 to January, 2014 that lesser flamingos where widely dispersed in lakes Big Momella and Rishateni and utilized mostly the inshore and offshore areas of the lakes. Algal blooms and scum that started to appear in February, 2014 in some areas in the shores of the lakes as a result of nutrient enrichment made the lesser flamingos unable to utilize such areas and this changed their distribution patterns in the lakes. The change was from sparse to clumped distribution. Clumped distribution pattern was observed when other areas were not being utilized by the flamingos because of the presence of scum and algal blooms that covered the surface of the waters.

This concurs with the previous studies by Tuite, (1978) that algal blooms have various implications on lesser flamingo distribution patterns. According to the findings high-density blooms of *A. fusiformis* can represent a food resource that is extremely high quality and energetically rich. However, availability of *A. fusiformis* is patchy in both space and time. Hence, the flamingo population becomes clumped at places where high-density *A. fusiformis* blooms occur, so they can take advantage of exceptionally good feeding conditions. When *A. fusiformis* is not available at a high enough density at any larger lake, lesser flamingos change to the exploitation of benthic diatoms, a low quality food obtained from the mudflats, unsheltered bays and even dying wetlands. However, due to limitations in the carrying capacity of diatoms, the population is forced to disperse widely.

Lesser flamingos tend to avoid such areas because scum and algal blooms have an effect not only on the food filtering process but also on water quality, alteration of algal species composition and the process of swimming for the lesser flamingos (William, 1999). In addition cyanobacteria are best known as the dominant species of most algal blooms and can produce a variety of toxins collectively known as cyanotoxins which can affect the feeding behavior of the lesser flamingos. Therefore, the presence of scum and algal blooms that appeared in the lakes could again be one of the factors that affected not only the patterns of distribution, feeding and habitat utilization but also the temporal fluctuations of the lesser flamingos in the Momella lakes ecosystem.

### 4.4 Lake morphometrics and lesser flamingo fluctuations

The decline in numbers of lesser flamingos in lakes Big Momella and Rishateni as observed in the study period significantly correlated with seasonal fluctuations in water level which was associated with changes in lakes configuration. The distortion of lakes shoreline configuration had some implications on the feeding mechanisms and temporal availability of lesser flamingos in the ecosystem. In November, 2013 it was observed in the findings of this study that when water depth was low the lakes could support large numbers of lesser flamingos. When the water depth was high due to increased rainfall especially in April, 2014, the numbers of lesser flamingos decreased in the lakes. This is because high water level submerged the shores that were highly utilized by lesser flamingos. This in turn affected the activities of the lesser flamingos in the sense that they were unable to utilize such areas for feeding, resting, roosting and display of courtship dances.

This concurs with the previous studies done by Githaiga (2003) that increase in water levels, either due to rains or inflows, can in one way or another alter not only the physicochemical parameters of the lake but also its shoreline configuration. The increased water levels can lead to shoreline submersion and thereby distort the lake shorelines which are very crucial for the feeding mechanisms and habitat utilization by the lesser flamingos. Annual variations in rainfall can affect not only the lake depth, surface area, but also the physicochemical composition of the aquatic ecosystems and lowland wetlands. Such variations can influence not only the feeding conditions, but also utilization patterns and temporal availability of lesser flamingos in the ecosystem (Romano *et al*., 2009). This fact is also supported previous findings by Mwaura (2009) that shoreline structure and variability are among the factors that have a strong influence on not only the number of species but also counts of water birds. This implies that variability in shoreline water levels can distort the shoreline configurations and thus affect the number of water birds utilizing the system. According to Tuite (1978) the mud- feeding behavior of lesser flamingos is possible only when water level in shallow areas is low to about 1 meter. Such low water levels allow lesser flamingos to exhibit either walk mud-feeding or swim mud-feeding and all these are possible if water levels are about 0.5 meter and between 0.5 to 1 meter respectively. With high water levels the filter feeding mechanism of the lesser flamingos is hampered. This is because lesser flamingos are not specialized swimmers like the Anatids and Pelicanids, but rather tend to filter feed while walking on the sediment substrate and this is possible only in shallow waters.

It was also observed in Lake Big Momella and Rishateni that increase in water depth was also associated with the appearance of algal blooms. This indicated that the increase in water level was also associated with changes in physicochemical parameters that led to the formation of algal blooms. According to Vareschi (1982), saline lakes are dynamic, discrete ecosystems with in-lake processes that are sensitive to fluctuating water levels, which result in changes in the composition of their algal species, affecting the flamingo food base. The in-lake processes that are sensitive to fluctuating water levels can at times be associated with algal blooms which vary from uni-algal assemblages of *A. fusiformis* to blooms of other algae of lower food quality for the lesser flamingo. All these can have noticeable implications on the feeding conditions and mechanisms for the lesser flamingos. Therefore lake morphometrics particularly fluctuations in water level in combination with other factors that were associated with the fluctuations in water level as previously explained could be one of the reasons accelerating the decline of the lesser flamingo populations inhabiting the Momella lakes ecosystem.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Summary of findings

The findings of this study indicated that there were notable variations with regard to physicochemical parameters of Lake Big Momella and Lake Rishateni. With the exception of water pH and salinity which remained fairly constant, all the other parameters which included temperature, electrical conductivity, dissolved oxygen and light transparence showed great variations during the study period. Vertical patterns also revealed that with the exception of water pH, all the other selected parameters which included temperature, dissolved oxygen and electrical conductivity showed great variations with depth. Such variations as indicated by the vertical patterns show that the Momella lakes are highly productive because of the high mixing of the waters.

High levels of nutrients particularly phosphorus and nitrogen were also observed in the lakes during the study period. The concentration of nitrogen was observed to be relatively higher than that of phosphorus during the study period in both lakes. This as explained previously could be due to the presence of birds in the lakes whose fecal materials contributed to the high levels of nitrogen in the lakes. Such high levels of nutrients in combination with the other factors like high temperature, electrical conductivity, dissolved oxygen and intense light created a good environment for the growth of algae in the lakes. This situation contributed to shifts in algal biomass and proliferation of algal blooms in the lakes.

Microscopic observation of the algal blooms revealed that the blue green algae in the lakes are composed of not only the common food species *A. fusiformis* for the lesser flamingos but also other harmful species like the *Microcystis* and *Anabaenopsis* that have already been shown by many research studies, such as those by Tuite, (1978), to be harmful to the lesser flamingos. These affected the feeding ecology of the lesser flamingos in the lakes because, apart from the toxins that they produce, they can also affect their food filtering mechanism.

With regard to lesser flamingo counts, the trend showed gradual decrease in numbers of lesser flamingo populations in the lakes during the study period. The gradual decrease in numbers as documented in the findings of this study was inversely related to algal biomass. Thus the numbers of lesser flamingos decreased with increase in algal biomass. This implies that the shifts in algal biomass, the appearance of algal blooms and the presence of harmful algae species like the *Microcystis* and *Anabaenopsis* probably were the reasons behind the temporal fluctuations in the numbers of lesser flamingos inhabiting the Momella lakes. The two harmful species contaminated the food of the lesser flamingos.

Rainfall variability during dry and wet seasons was observed to influence changes in lakes' configurations, which in turn affected not only the feeding behavior, but also habitat utilization, by lesser flamingos in the Momella lakes ecosystem. During the dry season lake shores with shallow waters accommodated large numbers of lesser flamingos as the shores were well exposed for the lesser flamingos to feed and perform other activities like courtship displays. The submersion of the shores due to increased precipitation during the wet season meant that lesser flamingos could not effectively utilize the shores due to increased water levels.

Generally, the feeding behavior and habitat utilization patterns of lesser flamingos in Momella lakes ecosystem as revealed in this study were influenced by an array of factors that operated in unison. The factors include; physicochemical parameters, nutrients, food for the lesser flamingos, algal blooms and morphometrics. Lesser flamingos being filter feeders and water dependent most often are very sensitive to water quality, food quantity and quality changes. Any change as regards the aforementioned factors can seriously affect the lesser flamingo feeding behavior and habitat utilization. All these as documented in the findings of this study could have contributed to the die offs observed, changes in utilization patterns and general decline in numbers of lesser flamingos inhabiting the Momella lakes ecosystem.

## 5.2 Conclusion

From this study it can be concluded that factors like changes in physicochemical parameters, high levels of nutrients, food contaminations, algal blooms and changes in lakes configurations influence the feeding behavior and utilization patterns of lesser flamingos in Momella lakes ecosystem in Arusha National Park. It has been observed that these diverse factors do not operate independently, but in unison to bring out the undesired consequences on the feeding ecology and habitat utilization by the lesser flamingos in the Momella lakes:

- Variations in the physicochemical parameters as observed in this study greatly influenced shifts in algal composition and proliferation of algal blooms in the study lakes.
- High levels of nutrients particularly phosphorus and nitrogen were the main driving factors that accelerated shifts in algal biomass and the growth algal blooms in the lakes. The proliferation of algal blooms was a clear sign that the water was not in good quality, especially at the onset of the rain season.

- Algal composition was again another problem that affected the food for the lesser flamingos. Just like the other Rift Valley saline lakes (e.g. Lake Bogoria) the blue green algae in the Momella lakes were composed of not only the *A. fusiformis*, but also other harmful algae species like the *Microcystis* and *Anabaenopsis*. These species contaminated the food of the lesser flamingos in the two lakes.
- Changes in shoreline configurations due to rainfall variability during the dry and wet seasons affected not only the feeding behavior, but also habitat utilization by the lesser flamingos in the two lakes. This implies that the rise and fall of shoreline water levels distorted the shoreline configuration of the lakes, which in turn affected the lesser flamingo habitat utilization and feeding mechanisms and hence their seasonal movement between the Eastern Rift Valley lakes.

## 5.3 Recommendations

### 5.3.1 Lake management

The following are the recommendations based on the results of this study for management actions in order to conserve these near threatened species in Momella lakes ecosystem:

1. Conservation and protection of Momella lakes ecosystem from being encroached by human activities like agriculture and livestock by Arusha National Park Managers and Arusha Municipal Council.
2. Conservation and protection of soil, water sources and catchment areas around Momella lakes ecosystem.
3. Establishment of several water level gauges in the lakes is of great importance for close monitoring of fluctuations in water levels. So far there is only one water level gauge established in Lake Big Momella.

### 5.3.2 Suggested areas for further research

There are still other aspects that need to be researched more and more as far as the feeding and habitat utilization ecology of lesser flamingos in Momella lakes ecosystem is concerned. The areas that need further research include;

1. Toxicological research to detect specific cyanotoxins that are lethal to the lesser flamingos in Momella lakes ecosystem.
2. Sources of nutrients especially phosphorus and nitrogen in Momella lakes ecosystem.
3. The impact of anthropogenic activities around Momella lakes ecosystem.

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## APPENDICES

### Appendix 1: Types of cyanotoxins and their effects on organisms

| Cyanotoxins | Genera of main producers | Chemical classification | Action mechanism |
|---|---|---|---|
| Hepatotoxins | | | |
| Microcystins<br><br>Nodularins<br><br>Cylindrospermopsins | *Anabaena*, *Planktothrix*,<br>Nostoc, *Anabaenopsis*<br><br>*Nodularia*<br>*Cylindrospermopsis raciborskii*,<br><br>*Aphanizomenon ovalisporum*, *Aphanizomenon zflos-aquae* | Cyclic<br>Heptapeptides<br><br>Cyclic Pentapeptídes<br><br>Guanidine alkaloids | Inhibition of protein of phosphatases type 1 and 2A<br><br>Inhibition of protein of phosphatases type 1 and 2A<br><br>synthesis as well as cytochrome P450 |
| Neurotoxins | | | |
| Anatoxin-a<br><br>Anatoxin-a(s)<br><br>Saxitoxins | *Anabaena*,<br>*Aphanizomenon*, *Planktothrix*<br><br>*Anabaena*<br><br>**Dinoflagellates**: *Alexandrium*, *Pyrodinium*, *Gymnodinium*<br>**Cyanobacteria**: *Anabaena circinalis*,<br><br>*Aphanizomenon sp.*, *Aphanizomenon gracile*, *Cylindrospermopsis raciborskii*, *Lyngbyawollei* | Alkaloid<br><br>Organophosphate<br><br>Carbamate alkaloids | Irreversible link to the nicotinic receiver S of acetylcholine<br><br>Irreversible inhibitor of acetylcholinesterase<br><br>Block sodium channels in nerve axons |
| Dermatotoxins | | | |
| Lyngbyatoxin-a<br><br>Aplysiatoxin<br><br>Lipopolysaccharides (LPS) | *Lyngbya*<br><br>*Lyngbya*, *Schizothrix*, *Planktothrix (Oscillatoria)*<br><br>Cyanobacteria in general | Alkaloid<br><br>Alkaloids<br><br>Lipopolysaccharides | Potent tumor promoters, acting through potentiating of protein kinase C (PKC).<br><br>Potent tumor promoters, acting through potentiating of proteinkinase C (PKC)<br><br>Inflammatory agents, gastrointestinal irritants |

**Appendix II: Geo-referenced positions of the sampling sites**

| Lake | Sampling site (S) | GPS location |
|---|---|---|
| **Lake Big Momella** | 1 | S 03$^0$ 13’ 445’’ E 036$^0$ 54’ 601’’ |
| | 2 | S 03$^0$ 13’ 410’’E 036$^0$ 54’ 385’’ |
| | 3 | S 03 13’ 633’’ E 036$^0$ 54’ 505’’ |
| **Lake Rishateni** | 1 | S 03$^0$ 13’ 969’’E 036$^0$ 54’ 427’’ |
| | 2 | S 03$^0$ 13’ 836’’E 036$^0$ 54’ 613’’ |
| | 3 | S 03$^0$ 14’ 084’’ E 036$^0$ 54’ 402’’ |

## Appendix III: Lesser and greater flamingo counts in the study lakes

| | | Big Momella | Rishateni | Tulusia | TOTAL |
|---|---|---|---|---|---|
| Nov. 2013 | **Adults** | **42,414** | **11,910** | **1,880** | **56,204** |
| | **Juveniles** | **1,500** | **585** | **440** | **2,525** |
| Dec. 2013 | **Adults** | **33,325** | **5,000** | **2,937** | **41,262** |
| | **Juveniles** | **1,700** | **140** | **560** | **2,400** |
| Jan. 2014 | **Adults** | **23,032** | **3,043** | **1,201** | **27,276** |
| | **Juveniles** | **5,750** | **755** | **393** | **6,903** |
| Feb. 2014 | **Adults** | **20,823** | **235** | **212** | **21,270** |
| | **Juveniles** | **5,220** | **48** | **60** | **5,328** |
| Mar. 2014 | **Adults** | **3,256** | **0** | **7** | **3,263** |
| | **Juveniles** | **229** | **0** | **24** | **253** |
| Apr. 2014 | **Adults** | **232** | **0** | **58** | **290** |
| | **Juveniles** | **26** | **0** | **19** | **35** |
| May 2014 | **Adults** | **256** | **0** | **55** | **311** |
| | **Juveniles** | **50** | **0** | **19** | **79** |

**Appendix IV: Monthly mean values (±SE) of physicochemical parameters in Lake Big Momella**

| **Parameter** | **November** | **December** | **January** | **February** | **March** | **April** | **May** |
|---|---|---|---|---|---|---|---|
| Temperature ($^0$C) | 23.2 ± 0.03 | 23.5 ± 0.09 | 24.4 ± 0.15 | 25.9 ± 0.09 | 26.5 ± 0.15 | 27.6 ± 0.23 | 26.8 ± 0.23 |
| Electrical Conductivity (µS/cm) | 34951.1 ± 0.29 | 35389.5 ± 0.25 | 39931.1 ± 0.52 | 40155.6 ± 0.53 | 40355.6 ± 0.38 | 40955.2 ± 0.16 | 40940.5 ± 0.17 |
| Dissolved Oxygen (mg $O_2$/l) | 12.2 ± 0.12 | 12.5 ± 0.17 | 12.3 ± 0.17 | 12.8 ± 0.23 | 15.6 ± 0.15 | 17.7 ± 0.32 | 15.4 ± 0.29 |
| Light Transparency (cm) | 28.3 ± 0.56 | 32.7 ± 0.37 | 35.8 ± 0.06 | 38.2 ± 0.18 | 38.2 ± 0.21 | 40.3 ± 0.23 | 39.5 ± 0.35 |
| Total Nitrogen (mg/l) | 2.9 ± 0.12 | 5.8 ± 0.29 | 15.2 ± 0.23 | 22.9 ± 0.18 | 30.4 ± 0.09 | 38.4 ± 0.38 | 36.6 ± 0.20 |
| Total Phosphorus (mg/l) | 0.08 ± 0.01 | 0.06 ± 0.01 | 0.17 ± 0.01 | 0.07 ± 0.01 | 2.63 ± 0.01 | 2.07 ± 0.02 | 0.2 ± 0.01 |

**Appendix V: Monthly mean values (±SE) of physicochemical parameters in Lake Rishateni**

| **Parameter** | **November** | **December** | **January** | **February** | **March** | **April** | **May** |
|---|---|---|---|---|---|---|---|
| Temperature ($^0$C) | 24.5 ± 0.17 | 24.7 ± 0.12 | 25.9 ± 0.12 | 26.8 ± 0.23 | 28.1 ± 0.20 | 27.3 ± 0.12 | 26.8 ± 0.12 |
| Electrical Conductivity (μS/cm) | 24378.4 ± 0.27 | 27508.9 ± 0.29 | 29605.6 ± 0.35 | 30853.3 ± 0.12 | 32105.6 ± 0.35 | 33115.7 ± 0.29 | 32120.5 ± 0.09 |
| Dissolved Oxygen (mg $O_2$/l) | 4.9 ± 0.12 | 6.5 ± 0.03 | 8.5 ± 0.15 | 13.7 ± 0.12 | 16.8 ± 0.17 | 20.6 ± 0.26 | 18.1 ± 0.20 |
| Light Transparency (cm) | 25.5 ± 0.23 | 26.7 ± 0.20 | 28.3 ± 0.23 | 35.5 ± 0.35 | 40.2 ± 0.17 | 39.2 ± 0.23 | 37.9 ± 0.26 |
| Total Nitrogen (mg/l) | 1.9 ± 0.12 | 2.2 ± 0.01 | 4.8 ± 0.26 | 7.2 ± 0.17 | 8.4 ± 0.12 | 9.2 ± 0.23 | 9.3 ± 0.23 |
| Total Phosphorus (mg/l) | 0.05 ± 0.01 | 0.07 ± 0.01 | 0.09 ± 0.01 | 0.98 ± 0.01 | 1.75 ± 0.03 | 0.86 ± 0.01 | 0.78 ± 0.02 |