ECOTOXICOLOGICAL ASSESSMENT AND WATERBIRD DISTRIBUTION IN SELECTED ALKALINE RIFT VALLEY LAKES, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

This work is dedicated to my lovely daughter Shantel, parents; David Barasa and Helen Wambaya, to my siblings Evans, Caren, Winnie and Brian and to my fiancé Patrick

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ABBREVIATIONS AND ACRONYMS

ATSDR	Agency for Toxic Substances and Disease Registry
AAS	Atomic Absorption Spectrometry
EPA	Environmental Protection Agency
HSAC	Hazardous Substances Advisory Committee
Hg	Mercury
Pb	Lead
Cd	Cadmium
Co	Cobalt
Mn	Manganese
Zn	Zinc
Cu	Copper
Cr	Chromium
Ni	Nickel
As	Arsenic
NMK	National Museums of Kenya
IBA	Important Bird and Biodiversity Areas
XRF	X-ray Fluorescence
ND	Not detected
Mv	Millivolts
Ppm	Parts per million

ABSTRACT

Ecotoxicology is the study of toxic chemical effects on living organisms at ecosystem, community or population levels. Heavy metals such as mercury (Hg), lead (Pb), Cadmium (Cd) and Chromium (Cr) are examples of common toxic chemicals that pollute the environment due to their persistence in the environment and resistance to biodegradation. The persistent pollutants enter water bodies through natural weathering process and anthropogenic activities. Kenya Rift valley lakes are prone to pollution by heavy metals due to increased industrial activities around lakes and the active natural volcanic activity in the area. Pollution is likely to influence the aquatic life including water birds distribution as a result of the effect on health and physiological parameters.

The study was carried out in six Kenyan Alkaline Rift Valley Lakes, Bogoria, Nakuru, Magadi, Oloiden, Elementaita and Crater Lake (Sonachi) with the aim to assess the ecotoxicology and its relationship with water bird distribution. The objectives of the study were to determine the levels of metal elements in water and sediment samples, describe the water birds inhabiting the Rift Valley lakes of Kenya and analyze the Kenya Rift Valley flamingo population trend from the year 1990 to 2015 based on secondary data.

High levels of lead (42ppm) above EPA 2007 benchmarks (36ppm) were detected in Lake Oloiden. Lakes Bogoria and Elementaita had high levels of Mn (3676.7 ± 6652.3 and 747.55 ± 510.95 respectively) above benchmark levels (631ppm) according to EPA 2007 benchmarks. The mean sediment concentrations for Zn, Pb, Ni, As and Hg were statistically significant ($P<0.05$) in all the six lakes. Apart from Zn, all other metal elements (Pb, Co, Mn, Cr, Cd, Fe and Cu) significantly varied in all water samples from the six selected lakes ($P<0.05$). The distribution of the water bird families for lakes Nakuru, Magadi, Elementaita, Oloiden, Bogoria and Crater were 11, 9, 9, 7, 6 and 4 respectively. There was no association between metal elements concentration and water bird distribution in all the selected six lakes ($P>0.05$). Flamingo population patterns from secondary data showed a great variation between years and between lakes due to inconsistency in annual counts and lack of data for some years.

It was concluded that concentration of metals in Kenya Rift Valley lakes has no effect on the distribution of water birds in the lakes; other factors other than metals may be associated with the distribution. Population trends of both lesser and greater flamingos in Kenyan Alkaline Rift Valley lakes are highly variable making future projections of their populations difficult and further studies should be carried out to establish the reasons for changes in flamingo population patterns. Bioaccumulation from the High Mn levels in lakes Bogoria and Elementaita and Pb in Oloiden might cause toxic effects to the aquatic living organisms and humans.

CHAPTER ONE

INTRODUCTION

1.1 Background

Ecotoxicology is the study of toxic chemical effects on living organisms at ecosystem, community or population level (Newman, 2008). Hazardous Substances Advisory Committee (HSAC), 2016). Heavy metals are some of the typical toxic chemicals in the surrounding since they occur naturally and persist in environment because they cannot be broken down into simpler substances (Reena *et al*., 2011) Examples of heavy metals include mercury, lead, cadmium, chromium and thallium (Raymond and Felix (2011).

There is a connection between heavy metals and water bodies (Samir and Ibrahim, 2008). Because heavy metals are part of the earth's crust, they get worn away through weathering process and once worn off; they collect in surface water or groundwater. Metal ions can be incorporated into food chains and concentrated in aquatic organisms to a level that affects their physiological state. Trace metals like Iron, zinc and copper, play a biochemical role in the physiological processes of aquatic fauna and flora. They are therefore absolutely necessary in small amounts. However, high levels of these important elements are toxic to aquatic organisms (Wolfgang, 2016).

Industrial wastes, agricultural effluents, sewage, natural weathering and surface run-off form the sources of metal elements in water bodies (Paul *et al.,* 2014).

Lake sediments are normally the terminal pathway of both natural and man - made components in the environment. Quality of sediments therefore forms a good indicator of pollution in water, where heavy metals and other organic pollutants get concentrated.

East African Rift valley lakes of Kenya are widely known for hosting water birds that solely depend on the wetlands. Pollution in these lakes therefore has direct impact on the wellbeing and distribution of these water birds. Lake Nakuru, Bogoria and Magadi for instance are bird paradise for many species. These species of birds are useful biological indicators of ecosystem health as they respond quickly to environmental changes.

1.2 General objective

To assess the ecotoxicology and water bird distribution of selected Kenya Rift Valley lakes

1.2.1 Specific Objectives

1. Determine the levels of heavy metals (Hg, Pb, Cr, Cd, Ni, As) and other elements (Mn, Co, Zn, Cu and F) in water and sediment of selected Kenya Rift Valley lakes.

2. Describe the water birds distribution in the Rift Valley lakes of Kenya

3. Analyze Kenya Rift Valley flamingo population trend based on secondary data from NMK from 1990 to 2015.

1.3 Justification

A healthy environment is the desired end point for environmental management, but without ongoing assessment and monitoring, the desired outcome is hard to achieve. The rapid deterioration of major ecosystems in the world calls for intensive and effective monitoring using operational indicators. Kenya Rift Valley Lakes are a home for many species of water birds that solely depend on the lakes for survival and birds respond quickly to changes in the environment. Birds can therefore be used as biological indicators of ecosystem health. Kenya Rift Valley Lakes are vulnerable to deterioration from both natural and anthropogenic pollution with heavy metals that might have an impact on water bird distribution across the lakes. Pollution due to heavy metals has been studied before in Kenya Rift Valley Lakes and elevated levels have been recorded. However, a study on the relationship between Eco-toxicological status and water bird distribution in these lakes has not been done. This study seeks to address this gap in order to contribute to understanding the relationship between pollution and water bird distribution.

CHAPTER TWO

LITERATURE REVIEW

Ecotoxicology is the study of the impacts of toxic chemicals on living organisms at ecosystem, community and population levels (Newman, 2008). Examples of toxic chemicals include; heavy metals, pesticides, asbestos, polychlorinated biphenyls, dioxin. Heavy metals are the most common inorganic chemicals polluting water bodies. Although heavy metals occur naturally through geological weathering process, anthropogenic activities also form a major source of these chemicals (Ochieng *et al.,* 2007; Konstantinos *et al.,* 2015). Once released to the environment, heavy metals persist for long since them are resistant to biodegradation (Agostinho *et al.*, 2012; Meenambigai *et al*., 2016).

East African rift valley lakes are vulnerable to heavy metal contamination due to increase in industrial and agricultural activities in the region. This poses a threat to water birds and other aquatic organisms that solely depend on these lakes. Water birds (waterfowls) are species of birds that that are ecologically dependent on wetlands such as lakes, rivers, swamps, lagoons, marshes and ocean (Waterbird Conservation for the Americas, 2007)**.** Examples of waterbirds include: flamingos, pelicans, cormorants, herons, ibises, egrets and geese (Birds in Backyards, 2016). Kenya rift valley lakes host many water birds and most of these lakes are part of Important Bird and Biodiversity Areas (IBAs) according to the 2007 Kenya IBA monitoring report. The lakes classified as IBAs include Lakes Magadi, Nakuru, Elementaita, Baringo, Naivasha and Bogoria (Kenya IBA report, 2007**).** The alkaline lakes are also known for provision of periodic feeding stations for enormous numbers of the nearly threatened lesser flamingo (*Phoeniconias minor).*

2.1 Heavy metals

Heavy metals occur naturally element, have a high atomic weight and a density 5 times higher than that of water (Klaus, 2010; Paul *et al*., 2014). Examples include mercury, lead, cadmium, chromium, Arsenic and thallium (Klaus, 2010; Barakat, 2011; Raymond and Felix, 2011). Heavy metals can induce toxicity at low exposure levels (Jä rup, 2003; Paul *et al.*, 2014). Trace elements such as copper, zinc, iron and manganese are essential elements in biological organisms since they play a key role in various biochemical and physiological processes however, they become noxious when they exceed certain concentrations (Monisha *et al*., 2014)

2.1.1 Mercury

Mercury exists naturally and also as man-made contaminant (Rice *et al*., 2014)**.** Three forms of mercury exist; metallic, organic and inorganic form (WHO, 2016). Metallic form is used in batteries, electrical switches and thermometers (ATSDR, 1999). It is also used in producing chlorine gas and in gold extraction. Combination of mercury with elements like sulfur, oxygen or chlorine, leads to formation of mercuric salts which are inorganic mercury (ATSDR, 1999) and are used in manufacture of fungicides, skin-lightening products. Mercuric chloride is used as a topical antiseptic and disinfectant agent. Organic form of mercury is when mercury combines with carbon and the most common organic form is methyl mercury (ATSDR, 1999). The three forms differ in their effects on various systems like the nervous, digestive, immunity and respiratory systems and on eyes, kidneys and skin. Mercury in the environment can be transformed to methyl mercury by bacteria which bio-accumulates in fish and shellfish (WHO, 2016). Sources of mercury exposure may include consumption of fish which have accumulated mercury by feeding on exposed lower organisms and exposure to various commercial products such as soaps, skin creams, vaccines and analgesics (Guzzi and Porta, 2008)

The nervous system is the vital repository for mercury exposure although the residual and transient systemic distribution of mercury has the ability to cause signs in other systems (Ceccateli *et al*., 2010). It causes the intereference with production of energy and P-450 enzymatic blockage and impairment of actin and tubulin systhesis which are vital components of neuronal cell structure (Kazantzis, 2002). Other systems affected include the digestive, renal, cardiovascular, pulmonary, reproductive and immune systems (Wada *et al*., 2009; Clarkson and Magos, 2006).

2.1.2 Lead

Native lead is a biologically non-essential toxic metal rare in the environment existing in several stable oxidation states that are absorbed and accumulated by aquatic and terrestrial organisms. Currently it is found in ore with silver, zinc and copper. Anthropogenic sources are major sources of environmental lead although it also occurs naturally.

The main sources of lead exposure include drinking water, food, industrial processes and smoking. House paint, gasoline, vehicle exhausts and storage batteries are also sources of lead. Lead also enters aquatic systems through erosion and leaching from the soil, domestic and industrial waste discharges.

Oxidative stress and ionic mechanism following lead exposure lead to cell toxicity (Monisha *et al*., 2014). These mechanisms cause changes in various biological processes such as maturation, apoptosis, enzyme regulation, ionic transportation and release of neurotransmitters (Flora *et al*., 2012). The overall presentation is neurological signs and death (Phil, 2010).

2.1.3 Cadmium

Cadmium is a by-product of zinc production (Monisha *et al*., 2014). It is used in batteries, and some alloys. Cadmium is also present in tobacco smoke, coatings, platings and pigments

(Bernard, 2008, Mutlu *et al*., 2012).Cadmium exposure can result from industrial waste discharges and consumption of plants with accumulated levels of cadmium (Satarug *et al*., 2011; Mutlu *et al*., 2012). Cadmium has adverse effects on enzymatic systems and induction of nutrient deficiency in plants (Irfan *et al*., 2013). Cadmium binds to protein cysteine in the liver causing hepatotoxicity and then circulates to the kidney where it accumulates causing nephrotoxicity. Zinc inhibition can occur when cadmium replace zinc in presence of metallothionein thus preventing zinc from action as a scavenger of free radicles (Castagnetto *et al*., 2002).

2.1.4 Chromium

Chromium is among the most abundant elements on earth's crust (Mohanty & Kumar, 2013). It occurs in several oxidation states but trivalent and hexavalent forms are the most common (Mohanty & Kumar, 2013).Chromium occur naturally from burning of oil and coal, petroleum, chromium steel, fertilizers, pigment oxidants and metal plating tanneries. Human activities sources include sewage and fertilizers (Ghani, 2011). High amounts of chromium can lead to the inhibition of erythrocyte glutathione reductase which interferes with reduction of methemoglobin to hemoglobin. Matsumoto *et al*., 2006 also demonstrated the ability of chromate compounds to induce DNA damage including chromosomal aberrations, alterations in transcription and replication of DNA.

2.2 Other elements

2.2.1 Copper

Copper sources include natural soil weathering, volcanic eruptions, forest fires, and intentional application to water, industrial discharges and sewage treatment plants (EPA, 2009). Natural sources of copper are volcanic eruptions, windblown dust and forest fires (EPA, 2009). Adverse effects include interference with behavior such as predator avoidance and migratory success, interference with juvenile growth and sensory system in fish (Landino, 2010). Copper is also associated with weakness, anemia and depression in birds.

2.2.2 Zinc, Cobalt and Manganese

Zinc is an essential element involved in regulating many enzymes. It is an antioxidant and immune-boosting supplement. It is found in all foods, soil, air and water. Too little zinc can cause reproductive effects and poor health. High zinc levels are toxic to crustaceans and many algae since it causes disruption of internal ionic balance. Excess zinc in mammals has effects on iron metabolism and also causes copper deficiencies. Zinc also interacts with the chemical lead potentiating its effects on body systems (Lennetech, 2016).

Cobalt is a trace essential element that is critical for formation of vitamin B12 and is widely distributed. However, excess dietary cobalt is toxic to animal.

Manganese is a naturally occurring essential element. The sources to water bodies include soil and rock erosion, mining activities, industrial wastes and leaching from man-made materials like dry-cell batteries. Over-exposure effects mainly involve the nervous and pulmonary system (ATSDR, 2016)

2.2.3 Analysis of metal elements

Analysis of metal elements is comprised of three steps: sampling, pre-treatment of the sample and analysis. The choice of the analytical technique depends on the cost, sensitivity (Limit of detection), physical state of the matrix and accessibility of the instrument. The common analytical techniques used to determine heavy metals in environmental matrices are: Atomic Absorption Spectrometry (AAS), Neutron Activation Analysis (NAA), Inductively Coupled Plasma Atomic Emission Spectrometry (ICP/AES), X-ray fluorescence (XRF), Inductively Coupled Plasma Mass Spectrometry (ICP/MS) and Ion Chromatography (IC) (Richard and

Martin 2005). In this project, AAS and XRF were chosen based on availability and cost of analysis.

AAS measure the concentration of elements and can be used to analyze the concentration of more than 62 different metals in a solution. It is sensitive to measure to parts per billion of a gram in a sample. AAS technique makes use of the wavelengths of light absorbed specifically by the element. They conform to the energies needed to promote electrons from one energy level to another. Atoms of different elements absorb particular wavelengths of light. Analyzing a sample to see if it contains a specific element means using light from that element. For example, with zinc, a lamp containing zinc emits light from excited zinc atoms that produce the right mix of wavelengths to be absorbed by any zinc atoms from the sample. The sample is atomized and a beam of electromagnetic radiation emitted from excited zinc atoms is passed through the vaporized sample. Some of the radiation is absorbed by the zinc atoms in the sample. For quantitative analysis, absorbance of a series of solutions of known concentration are measured. A calibration curve and the equation for the line are used to determine an unknown concentration based on its absorbance (AA-Perkin Elmer guide).

XRF involves emission of an X-ray photon after ionization of the atom by a primary beam X-ray. An X-ray from the tube impact in the sample where it interacts with an electron from one of the inner shell of the atom. It knocks the electron out of its orbital. This leaves a void which will be promptly filled by an electron from an outer shell. This electron has a higher energy than the electron it is replacing. The excess energy is expelled in the form of an X-ray with a wavelength specific for the atom. XRF requires minimal sample preparation, it is transportable for field analyses and analyzes many elements simultaneously in a given sample.

2.3 Importance of water birds

Water birds (waterfowl) are species of birds that are ecologically dependent on wetlands such as rivers, swamps and lakes (Water bird Conservation for the Americas, 2007). Changes in wetlands ecosystem health affects water birds directly and within a short period since birds respond quickly to any slight change in the environment.

2.3.1 Role in biological invasion

Water birds have been identified as possible contributor to biological invasions (Green and Andy, 2016). For instance, gulls and cormorants are important as vectors of dispersing aliens such as invertebrates and microbes like phytoplankton (Stoyneva, 2015). Aliens are dispersed following ingestion or attachment to body parts such as plumage or bills. Dispersal can also occur during preying on vectors like fish and during nest making (Green and Andy, 2015). Water birds are likely to contribute to future invasion ecology.

2.3.2 Bio-monitors of the ecosystem health

Water birds that rely on wetlands for food, nesting and breeding can be used as environmental indicators (Ogden *et al*., 2014) because they are high in trophic levels, able to move in response to both opportunity and adversity, and are easy to notice and quantify in both space and time. For a bird to be chosen as an indicator, it has to satisfy three prerequisites which include; mechanistic links between ecological differences and bird parameters, matching of links appropriately in timing, type, and space with the interested environmental variable and lastly, the parameter being monitored by avian has to be of predictive value in relation to the wider ecosystem function. The interference is of little importance if other resources or species are not affected (Ogden *et al*., 2014).

Changes in living birds, both at population and individual levels, are indicators of climate change and bird fossils have been used as evidence of how past climates were (Peterson and Roger, 2016). Water birds in the selected Kenya Rift Valley Lakes can be used as indicators of changes in the ecosystem.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study sites

The study area covers six alkaline lakes of Kenyan Rift valley namely Magadi, Bogoria, Oloiden, Crater (Sonachi), Elementaita and Nakuru. The Kenyan Rift valley is a home to lakes three of which are freshwater and these include Baringo, Naivasha and Turkana. Alkaline lakes include Bogoria, Elementaita, Logipi, Magadi, Nakuru, Oloiden and Crater. The soda lakes of Eastern Rift valley have crystallised salt turning the shores white and are famous for the large flock of flamingo that feed on green algae and crustaceans.

Lake Magadi is the southernmost lying at $1^0$52'S $36^0$16'E, north of Tanzania's Lake Natron. It is approximately 100 Km^2 and is well known for its wading birds. During dry season, it is 80% covered by soda.

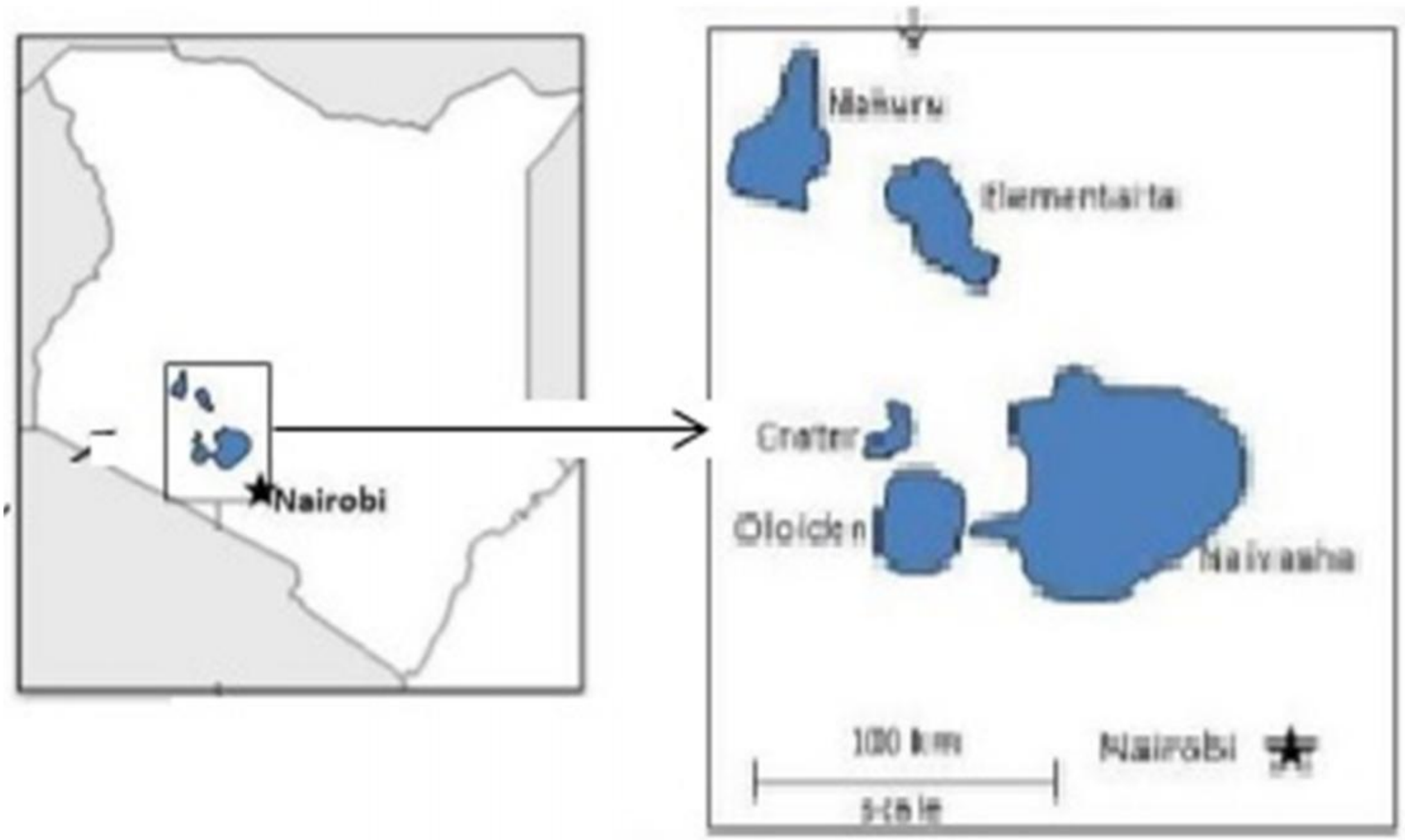


Figure 3. 1: Map of Rift Valley Alkaline Lakes in Kenya (Source: Barasa et al 2017)

Lake Bogoria is about 65km to the north of Nakuru at an altitude of 970m above sea level. The lake has a surface area of 33km^{2}and lies within a National Reserve. The lake is narrow with a maximum length of 34km and maximum width of 3.5km and is shallow with a depth of about 10m. The dominant salts are sodium carbonate and sodium hydrogen carbonate. It has an average PH of 10.2. Lake Bogoria also contains the highest number of true geysers in Africa. Other hot springs discharge directly into the lake from the floor. Lake Bogoria National Reserve has more than 350 species of waterbirds. It is the only reliable feeding site for lesser flamingo in East

Africa. Crater Lake (Sonachi) and Lake Oloiden are closed alkaline water lakes in the vicinity of Lake Naivasha. The water level in the two lakes is maintained by sub-surface inflow from Lake Naivasha (Verschuren, 1999a) Lake Sonachi is positioned Geographically at 00^0 47′S, $36^0$15′E with a surface area of about 0.18Km^2 and 5.3m depth (Verschuren, 1999). Lake Oloiden is a former bay of Lake Naivasha with a hydrologically closed basin (Verschuren *et al*., 2000).

Lake Elementaita is a protected area due to birdlife fame, the lake is a protected area. Elementaita attracts visiting flamingos that feed on insect larvae, crustaceans and suspended blue-green algae in the lake. The lake is normally very shallow (<1m deep). Due to these conditions, millions of birds which formerly used the lake as breeding site are said to have migrated to Lake Natron in Tanzania.

Lake Nakuru has a surface area of 5 to 45km^2 located at 36^0 05’ E, 00^0 24’ S and stands at an altitude of 1754m above the sea level. The lake has an average PH of 10.5. The main ions are sodium, bicarbonate and carbonate. Lake Nakuru is supplied by rivers Makalia, Larmudiac, Naishi, Nderit and Njoro all of which are seasonal. Treated wastewater from Nakuru town also discharges to the lake. There is also some recharge from the natural springs on the northern end of the lake. Lake Nakuru is located close to Nakuru town, which is an important highly industrialized town and has ongoing agricultural activities.

3.2 Sample size determination and collection

3.2.1 Sample size determination

Sample size was done using purposive sampling technique. The lakes were selected based on accessibility. Water and sediment sampling sites were chosen purposively depending on site characteristics and accessibility.

3.2.2 Samples collection

Water samples were collected in plastic containers (Figure 3.2) and stored in cool boxes for transportation whereas soil sediment samples were collected in zip lock plastic bags. The samples were labeled before packaging (Figure 3.3).

Figure 3. 2 : Author collecting water sample at Lake Nakuru

Figure 3. 3: Author labeling samples before storage

3.3 Laboratory analysis

3.3.1 Water sample preparation for heavy metal analysis

Duplicate water samples were prepared by measuring 50ml of water into a beaker, adding 2ml of concentrated nitric acid and heating the contents on a hot plate to reduce the volume to 10ml. The mixture was filtered into a 50ml volumetric flask and topped to the mark with de-mineralized water ready for analysis.

3.3.2 Soil sediment sample preparation for heavy metal analysis

The sediment was first dried in an oven at $60^{o}C$ overnight before crushing into powder using a pulverizer. Each pulverized sediment sample was well mixed and 2.5g weighed into a 250ml beaker before adding 20ml of water to make sludge. Concentrated nitric acid (20ml) was then added to the sludge and the contents heated on a hot plate at 130°C for 1 hour without spurting to reduce the volume to 10ml. this was then cooled and filtered into 50ml volumetric flask, washed carefully with hot water and then topped to the mark ready for analysis.

3.3.3 Sample preparation for fluoride analysis

3.3.3.1 Water sample preparation

Three (3) ml of water samples was measured into a graduated plastic tube and 0.3mls of Total Ionic Strength Adjustment Buffer 111 (TISAB111) added ready for fluoride analysis by potentiometric method.

3.3.3.2 Soil sediment preparation for fluoride analysis

The sample was weighed (30g) on aluminum foil papers and dried in an oven at $105^{o}C$ overnight. The dried sample was then crushed into powder using a mortar and pestle and 50mg of the crushed sample weighed into propylene tube and 0.4mls of concentrated per-chloric acid/nitric acid mixture added to the sample in the fume chamber. In digestion propylene tube, 2.6mls of base mixture (7.8m Sodium Hydroxide + 1m Tri-sodium Citrate) at a ratio of 3:10 was added. The preparation was incubated at $60^{o}C$ in an oven for 1 hour. This was left to stand on bench to cool to room temperature and then shaken vigorously before pouring the mixture into graduated tube ready for analysis.

3.3.4 Analysis of heavy metals

Elemental mercury and arsenic in sediments were analyzed using X-ray fluorescence analyzer. Cadmium, chromium, lead, manganese, cobalt and copper were analyzed using flame atomic absorption spectrometer. Before reading the samples, standards of known concentrations for each metal were run to generate the standard calibration curves before reading the samples. To ensure accuracy and precision, a standard was read after every five samples to ensure the readings are within the expected concentrations.

3.3.5 Fluoride analysis

Potentiometric method was used (Ion selective electrode) (EPA 1996 method 9214). The standards of 0.05, 0.1, 1 and 10ppm were run in duplicates and the average calculated and the standard calibration curve drawn using the standard readings. Fluoride concentration in samples was determined using the calibrated standard curve (figure 3.4 and 3.5).

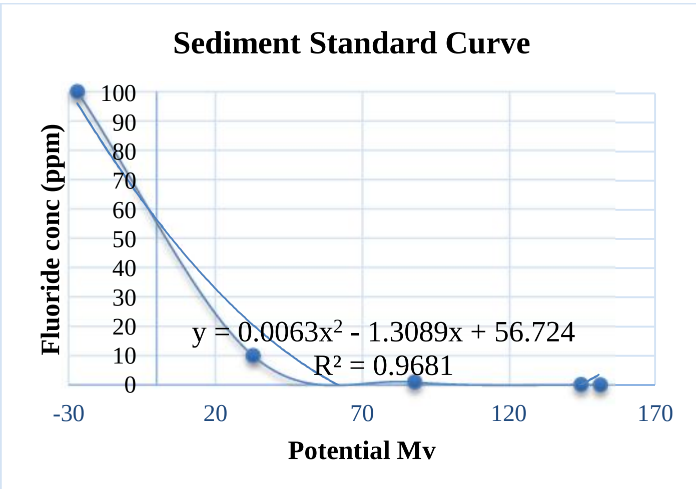


Figure 3.4: Fluoride sediment standard curve

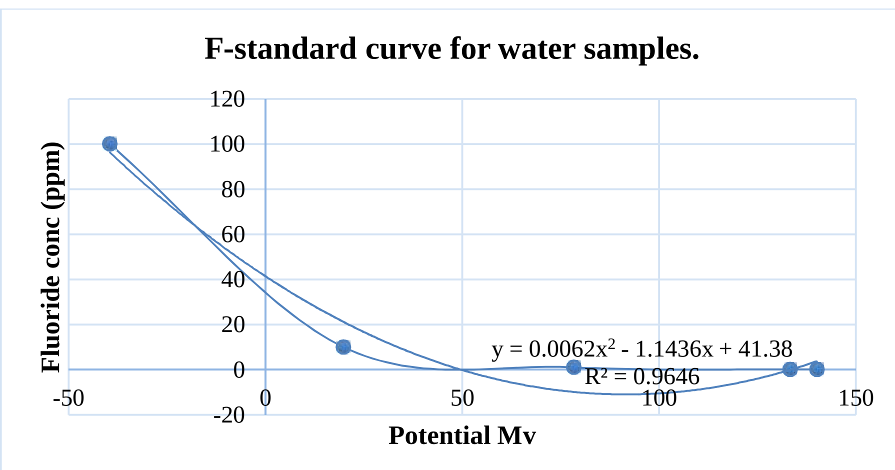


Figure 3.5: Fluoride standard curve for water samples

3.4 Analysis of flamingo population trend

Flamingo population trend was determined by desktop survey of secondary data from online sources and unpublished data from the National Museums of Kenya (NMK).

3.5 Water birds identification

Water birds along drive ways, at sampling sites and within visibility were observed using binoculars, identified using bird guide book by Zimmerman. Identification was confirmed by an ornithologist from the National Museums of Kenya (NMK)

3.6 Data management

Data obtained was entered into Microsoft Excel® spread sheet, cleaned and then exported to Stata® for analysis. The means, standard deviations, maximum and minimum levels to determine toxicant levels within the six lakes were obtained. One Way ANOVA test was used to analyse the variation between and within the lakes. Chi-square test on the other hand was used to test the association between metals concentration and water bird distribution among the selected rift valley lakes. Graphs and tables on flamingo populations were created using Microsoft Excel®.

CHAPTER FOUR

RESULTS

4.1 General findings for the lakes

Flamingos (*Phoenicopteridae*) were only observed in small numbers at Lake Magadi and Lake Bogoria. Crater Lake had only one lesser flamingo (*Phoeniconias minor*). Green algae (*Arthrospira fusiformis*) bloom; the main food for flamingos was only observed in Lake Bogoria. The specific findings per lake are highlighted in the following sections.

4.1.1 Lake Oloiden

Changes in biodiversity of the lake were observed with presence of birds and fish that had not been identified at the site. For instance, King fisher birds, Tilapia fish which were not there during the last visit in 2013 were present and fishing activities were evident (Muchemi pers com) (Figure 4.1). The riparian vegetation had disappeared and water hyacinth was present at the lake shores indicating a potential future invasion by this noxious water weed (Figure 4.2). Some of the bird species observed such as Pelicans, Kingfisher and Cormorants that are piscivores were indicators of fish presence. Presence of water hyacinth, Piscivores and Tilapia fish were indicators of the lake water becoming fresh. Residents found around the lake explained about the fresh water spillway that connects the alkaline lake Oloiden and the freshwater lake Naivasha. Cattle and goats were also observed watering at Kongoni beach of the lake.

Figure 4. 1: Tilapia fishing at Lake Oloiden

Figure 4. 2: Water hyacinth (Eichornia crassipes) (arrow) at the shores of Lake Oloiden

4.1.2 Crater Lake (Sonachi)

Besides 7 little grebes and common sandpiper, a single lesser flamingo (*Phoeniconias minor*) was observed with an *"Inform Nairobi Museum"* metal ring number D4352. The initial ringing details from National Museums of Kenya showed that the bird was ringed at the same Lake in late 2015. This showed that the bird had not moved since the time of ringing.

4.1.3 Lake Nakuru National Park

No flamingos observed in Lake Nakuru during the study. Sandpipers and relatives (*Scolopacidae),* and ducks and geese (*Anatidae)* bird species dominated the lake. Other water birds observed in the lake are shown in table 4:1. The water levels had risen greatly submerging the adjacent buildings. The sewage treatment plant which is located inside the park was poorly managed and contaminants could be spilling to the lake.

4.1.4 Lake Bogoria

An estimated 1400 flamingos were observed and algal bloom (Figures 4.3 and 4.4) was also evident indicating presence of flamingo food at that time. Other water birds observed are shown in table 4.7. Increased water levels submerging buildings around the lake. Some of the springs had been submerged by the rising water levels.

Figure 4. 3: The author and other team members assessing algal Bloom (arrow) at the shores of Lake Bogoria

Figure 4. 4: Algal bloom (arrow) at the shores of Lake Bogoria

4.1.5 Lake Magadi

Most of the lagoons around the factory were dry. The southern lagoons had over 300 chestnut-banded plovers, a species whose known largest population in Kenya is from this wetland. Flamingos (approximately 476) in number were estimated by physical counting.

4.1.6 Lake Elementaita

Twenty three pelicans were observed roosting on trees.

4.2 Fluoride analysis

Table 4.1 shows the mean concentration of fluoride in ppm for both sediment and water samples collected from the six Rift Valley lakes. All sites had fluoride in water samples (figure 4.5).

All sites except Oloiden and Nakuru had fluoride in sediments. Lake Magadi had highest mean concentration (182.64 ± 41.849) of fluoride in water samples followed closely by Lake Bogoria (170.23 ± 0.81). Lakes Nakuru and Oloiden recorded the least concentration of fluoride in water samples, 33.11 ± 46.86 and 39.18 ± 1.28 respectively.

Fluoride levels in sediment samples were lower compared to their respective water samples. Sediments from Lake Elementaita and Crater Lake had significantly higher levels of fluoride, 26.94 ± 9.93 and29.6 ± 11.05 respectively as compared to other lakes (Table 4.1).

Table 4. 1: Mean fluoride concentrations in sediment and water samples (Mean ± SD) from the six Rift Valley Lakes, Kenya

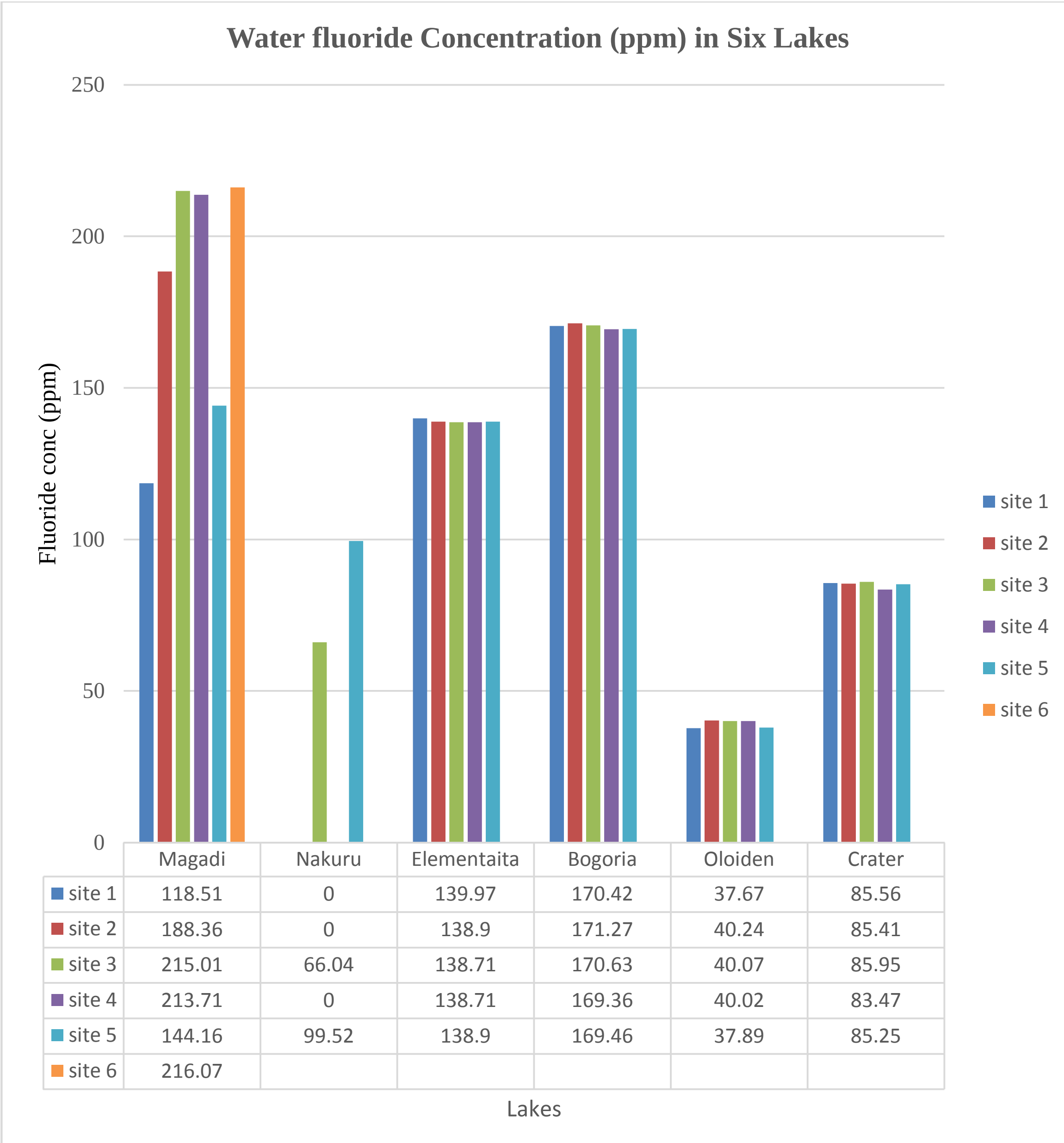
Site	N	Water	N	Sediment
L. Bogoria	**5**	**170.23 ± 0.81**	**5**	**3.92 ± 5.37**
L. Oloiden	**5**	**39.18 ± 1.28**	**5**	**ND**
L. Nakuru	**5**	**33.11 ± 46.86**	**5**	**ND**
L. Magadi	**6**	**182.64 ± 41.849**	**6**	**3.47 ± 5.02**
L. Elementaita	**5**	**139.04 ± 0.53**	**5**	**26.94 ± 9.93**
L. Crater	**5**	**85.13 ± 0.96**	**5**	**29.6 ± 11.05**

Key:

n - Number of samples

ND- not detected

SD –standard deviation



	Magadi	Nakuru	Elementaita	Bogoria	Oloiden	Crater
site 1	118.51	0	139.97	170.42	37.67	85.56
site 2	188.36	0	138.9	171.27	40.24	85.41
site 3	215.01	66.04	138.71	170.63	40.07	85.95
site 4	213.71	0	138.71	169.36	40.02	83.47
site 5	144.16	99.52	138.9	169.46	37.89	85.25
site 6	216.07					

Figure 4. 5: Water fluoride concentration (ppm) per lake

In Lake Nakuru, fluoride was only detected at around WCK hostels (site 3) and after the causeway (site 5). No fluoride was detected at the sewage (site 4), Njoro River (site1) and Makalia river (site2) inlets. High levels of fluoride were recorded in Lakes Magadi and Bogoria (figure 4.5). Lake Oloiden and Crater Lake had relatively lower levels of fluoride as compared to other lakes.

In lakes Elementaita and Crater, the samples were collected from one site. Highest levels of fluoride were detected in Lake Magadi samples from around Southern lagoon 2, western lagoon and at the factory causeway.

Sediment samples had relatively lower concentrations of fluoride as compared to respective water samples. All sites from Crater Lake had detectable levels of fluoride in sediments with a mean concentration of 29.6ppm ± 11.05ppm. Lakes Nakuru and Oloiden had no detectable levels of fluoride (Figure 4.6). All sites in Lake Bogoria had no detectable levels of fluoride in sediment except sediment from site 5 (Hot spring area) 10ppm and site 2 (Chebuluny swamp) with 9.6ppm.Despite recording highest levels of fluoride in water samples from Lake Magadi, the sediments had very low levels ranging from 0-13.06ppm.

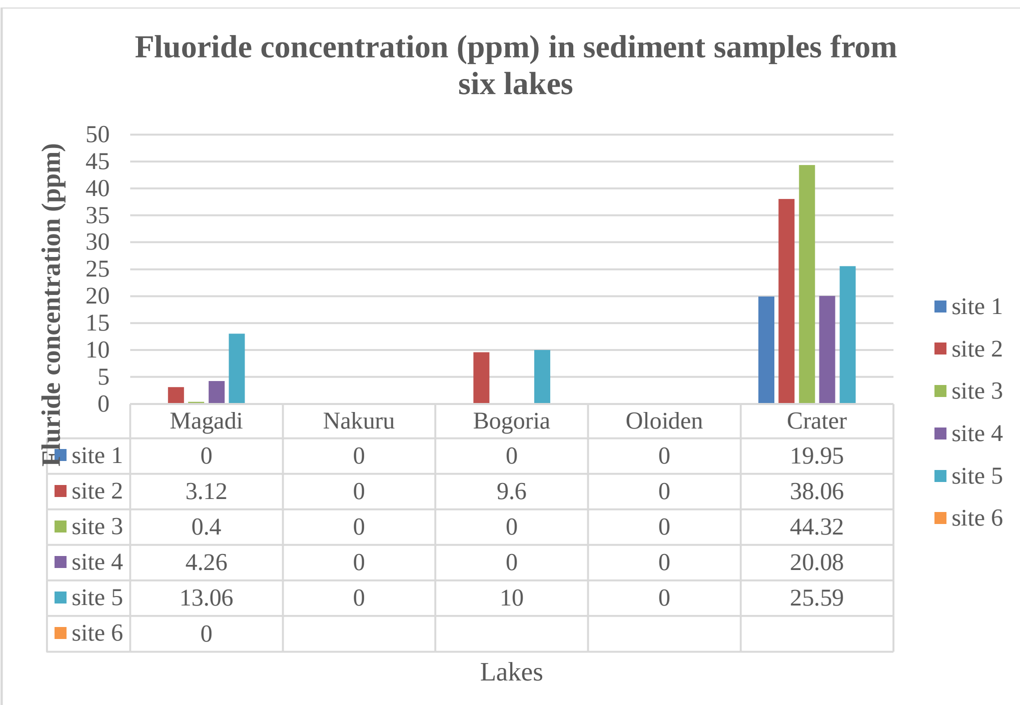


Figure 4. 6: Fluoride concentrations (ppm) in sediment samples for six Rift Valley lakes, Kenya

4.3 Results for Metal Elements analyzed by Atomic Absorption Spectroscopy

The mean sediment concentrations of Manganese (Mn), Cobalt (Co), Copper (Cu), Zinc (Zn), Cadmium (Cd) and Chromium (Cr) which were analyzed by atomic absorption spectrometer are shown in Table 4.2. High levels of Mn above the threshold limit were detected in Lakes Bogoria and Elementaita (Table 4.2). Cd was not detectable from all the six lakes (detection limit 0.005ppm). Co, Cu, Zn and Cr were below the threshold limits according to EPA 2007 (Table 4.2).

Table 4. 2: The mean concentration (ppm) of sediment samples using Atomic Absorption Spectrometry

Site	n	Mn	Co	Cu	Zn	Cd	Cr
Nakuru	5	326 ± 178.72	100.82±210.77	8.26±6.0425	57.236±42.941	ND	0.196±0.08173
Magadi	6	249.91±92.405	11.52±5.836	8.9233±3.3382	26.413±7	ND	0.15667±0.06377
Oloiden	5	65.74±14.304	11.86±7.1365	1.865±1.466	16.14±5.9053	ND	0.295±0.20936
Crater	5	185.7±60.558	27.148±13.709	9.272±2.597	22.136±6.787	ND	0.215±0.03416
Bogoria	5	3676.7±6652.3	16.725±7.7662	3.93±2.5429	54.556±42.361	ND	0.204±0.07403
Elementaita	5	747.55±510.95	15.075±6.935	7.268 ± 16.252	18.068±6.9173	ND	0.224±0.0555
Benchmark levels		631		32	121	1.0	43

Benchmark levels for sediment concentrations (from EPA (2007), bulk sediment toxicity benchmarks for benthic macroinvertebrates;

Key: Mn – manganese, Co – Cobalt, Cu – Copper, Zn – Zinc, Cd – Cadmium, Cr – Chromium, ND – not detected, n – Number of samples

In water samples, Lake Magadi had high levels above threshold limits (table 4.3) of Co, Cu, Zn, Cr and Pb. All lakes recorded high levels of Cr and Zn above the threshold limits (table 4.3). Lakes Nakuru and Magadi recorded high levels above the threshold limit (0.0005ppm) of lead in water samples (0.0015ppm and 0.0118ppm respectively (Table 4.3). Cadmium was not detected in any of the six lakes. Apart from Zinc, all other metal elements were significantly varied in all water samples from the six lakes ($P<0.05$).

Table 4. 3: Mean concentration (ppm) of water samples using Atomic Absorption Spectrometry

Site	Mn	Co	Cu	Zn	Cd	Cr	Pb
Nakuru	0.00433±0.00351	ND	ND	0.095±0.14256	ND	0.7958±0.0725	0.0015±0.00071
Magadi	0.00467±0.00234	2.3482±0.98588	0.04±0.01414	0.05083±0.02457	ND	1.2238±0.19708	0.0118±0.00319
Oloiden	0.0054±0.00055	ND	ND	0.0488±0.00084	ND	1.335±0.01037	ND
Crater	0.0048±0.00045	ND	ND	0.0512±0.00045	ND	1.3658±0.00694	ND
Bogoria	0.0064±0.00089	0.1742±0.04707	ND	0.1526±0.21657	ND	1.3918±0.04094	ND
Elementaita	0.0052±0.00045	ND	ND	0.0552±0.00045	ND		
Benchmark	0.12	0.023	0.003	0.036	0.000009	0.011	0.0005

Benchmark levels for sediment concentrations (from EPA (2007) bulk sediment toxicity benchmarks for benthic macroinvertebrates;

Key: Mn – Manganese, Co – Cobalt, Cu – Copper, Zn – Zinc, Cd – Cadmium, Cr – Chromium, Pb – Lead, ND – not detected

Table 4.4 and 4.5 below shows the maximum and minimum levels of element concentrations in ppm for sediment and water samples respectively.

Table 4. 4: Maximum and minimum levels of sediment samples in ppm

	Mn		**Co**		**Cu**		**Zn**		**Cd**		**Cr**	
Site	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Nakuru	175.62	560.01	0.78	477.8	2.32	16.26	17.04	109.8	ND	ND	0.08	0.26
Magadi	117.44	401.8	6.72	22.88	6.04	15.4	21.28	39.96	ND	ND	0.06	0.24
Oloiden	54.86	86.14	4.78	21.3	0.16	3.72	7.86	24.56	ND	ND	0.06	0.5
Crater	129.3	279.8	11.3	47.9	4.8	11.16	11.62	30.14	ND	ND	0.18	0.26
Bogoria	180.8	15562	9.86	24.44	1.38	6.68	18.76	104.6	ND	ND	0.12	0.3
Elementaita	99.74	1480.6	5.28	21.22	ND	ND	11.42	28	ND	ND	0.16	0.3

Key: Mn – Manganese, Co – Cobalt, Cu – Cobalt, Zn – Zinc, Cd – Cadmium, Cr – Chromium, ND – not detected

Table 4. 5: Maximum and minimum levels in ppm of metal elements in watersamples

Site	Mn		Co		Cu		Zn		Cd		Cr		Pb	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Nakuru	0.001	0.008	ND	ND	ND	ND	0.029	0.35	ND	ND	0.71	0.895	0.001	0.002
Magadi	0.002	0.008	0.637	3.109	0.03	0.05	0.004	0.076	ND	ND	0.914	1.416	0.007	0.014
Oloiden	0.005	0.006	ND	ND	ND	ND	0.048	0.05	ND	ND	1.327	1.352	ND	ND
Crater	0.004	0.005	ND	ND	ND	ND	0.051	0.052	ND	ND	1.361	1.378	ND	ND
Bogoria	0.006	0.008	0.133	0.253	ND	ND	0.054	0.54	ND	ND	1.33	1.432	ND	ND
Elementaita	0.005	0.006	ND	ND	ND	ND	0.055	0.056	ND	ND	0.413	1.439	ND	ND

Key: Mn – Manganese, Co – Cobalt, Cu – Cobalt, Zn – Zinc, Cd – Cadmium, Cr – Chromium, ND – not detected

4.4 Elements analyzed by X-ray Fluorescence (XRF)

Nickel (Ni), Arsenic (As), Mercury (Hg) and Lead (Pb) were the metal elements analyzed by XRF in sediment samples. This was the available method for Pb analysis after the Pb lamp used in AAS became faulty. There were no detectable levels of Nickel (Ni), Arsenic (As) and Mercury (Hg) in Lake Nakuru. Only two sites had detectable Pb levels; 50ppm above threshold limit (36ppm) at sewage inlet (site 4) and 30ppm after the causeway (site 5).

In Lake Magadi, Nickel (Ni) was only detectable at the second southern lagoon (site 3) at a concentration of 20ppm. Lead concentration of 40ppm was detected at the spring area (site 2).

Higher levels of lead were detected in Lake Oloiden with an average of 42ppm which is above the threshold limit (36ppm).. Traces below threshold limits of arsenic and Nickel were also detected at an average of 4ppm for the two metal elements.

Nickel (Ni), Lead (Pb) and Mercury (Hg) were below the detection levels in Crater Lake. However, traces of Arsenic metal element were detectable at an average concentration of 6ppm which is below threshold levels (9.8pm).

Pb and Hg were not detectable in Lake Bogoria. Arsenic above threshold limit (9.8 according to EPA 2007 standards) was only detected at hot spring (site 5) at a concentration of 10ppm. All sites except hot spring area had significant levels of Ni with the (site 2) around Chebuluny swamp having highest concentration of 100ppm (threshold limit 23ppm) followed by the site at entrance to Wasekes river (site 1) at northern part of the lake with the concentration of 50ppm, 20ppm near the water meter (site 3) and lastly 20ppm at site 4 which was the only site with flamingos. The mean concentration of 38 ±38.99 ppm Ni above threshold limit (23ppm) was found in Lake Bogoria.

As, Hg and Pb were below the detectable limits in Lake Elementaita. Only traces of Nickel were recorded at an average of 2ppm.

The variation in concentrations of all the four metals (As, Ni, Pb and Hg) were significantly different in the six lakes ($P<0.05$).

Table 4.6: Mean concentration of metal elements (Ni, As, Hg and Pb) in ppm for the six Kenya Rift Valley Lakes

Site	n	Ni	As	Hg	Pb
Nakuru	**5**	**ND**	**ND**	**ND**	**16±23.022**
Magadi	**6**	**3.3333±8.165**	**ND**	**ND**	**6.6667±16.33**
Oloiden	**5**	**4±5.4772**	**4±5.4772**	**ND**	**42±27.749**
Crater	**5**	**ND**	**6±5.4772**	**ND**	**ND**
Bogoria	**5**	**38±38.987**	**2±4.4721**	**ND**	**ND**
Elementaita	**5**	**2±4.4721**	**2±4.4721**	**ND**	**ND**
Benchmark levels		**23**	**9.8**	**0.18**	**36**

Benchmark levels for sediment concentrations (from EPA (2007), bulk sediment toxicity benchmarks for benthic macroinvertebrates;

Key: Ni – Nickel, As – Arsenic, Hg – Mercury, Pb – Lead, ND – not detected

4.5 Birds sighted at or around the lakes

An estimate of 4711 birds at or around the lakes were observed and identified during the study. Of the six lakes, Bogoria, Magadi and Nakuru had a higher bird density with estimated figures of 1542, 1471 and 1142 respectively (figure 4.7); compared to Lake Elementaita, Oloiden and Crater Lake. In diversity, Lake Nakuru was the most diverse with 23 different bird families (Appendix 6). The number of bird families in other lakes were; Magadi 15 families, Bogoria 13 families, Elementaita 9 families, Oloiden 7 families and 6 families for Crater Lake (Appedix 6).

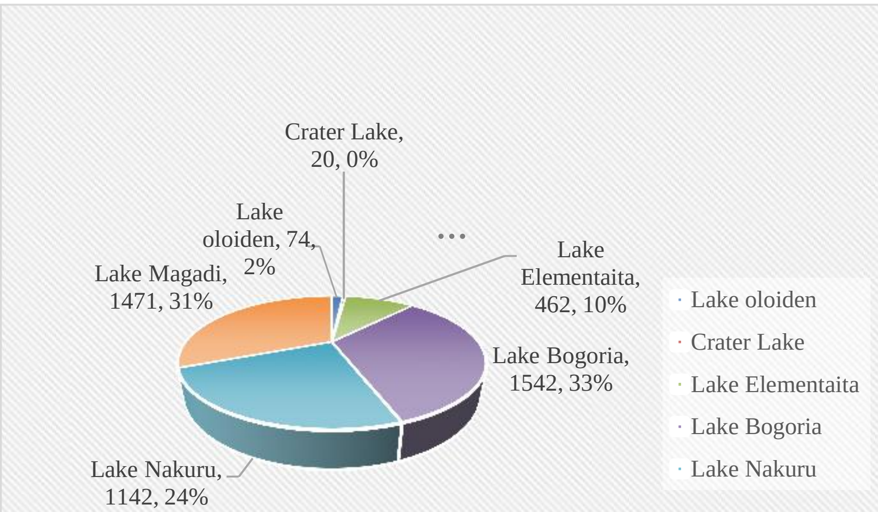


Figure 4. 7: Water birds density in lakes Nakuru, Magadi, Oloiden, Elementaita, Crater and Bogoria

4.6 Waterbird families sighted and identified

A total of 15 waterbird families were identified across the six lakes (Table 4.7).*Phoenicopteridae* family which comprises flamingos was the most abundant with an estimate of 1877 lesser flamingos (*Phoeniconias minor*) followed by sandpipers(*Scolopacidae)*(862)and stilts (*Recurvirstridae)*(453)families across the lakes. The distribution of water bird families for lakes Nakuru, Magadi, Elementaita, Oloiden, Bogoria and Crater were 11, 9, 9, 7, 6 and 4 respectively. African fish eagle of the family *Accipitridae* was sighted at Lake Oloiden.

4.7 Water bird distribution in relation to metal concentration

The concentration of metal elements in both water and sediment samples did not influence the distribution of water birds in the selected Rift Valley lakes (P>0.05, appendices 5 – 14).

Table 4.7: Water bird families identified at the Lakes

Family	**Lake Oloiden**	**Crater Lake**	**Lake Elementaita**	**Lake Bogoria**	**Lake Nakuru**	**Lake Magadi**	
Phoenicopteridae: flamingos	0	1	0	1400		476	**1877**
Scolopacidae: sandpipers and relatives	0	4	250	50	367	191	**862**
Recurvirostridae: stilts and avocets	0	0	3	24	69	357	**453**
Anatidae: ducks and geese	0	0	5	5	207	20	**237**
Pelecanidae: pelicans	15	0	53	0	52	0	**120**
Ardeidae: herons, egrets and bitterns	5	0	54	1	45	8	**113**
Threskiornithidae: ibises and spoonbills	0	0	78	0	24	1	**103**
Phalacrocoracidae: cormorants	35	0	0	0	35	0	**70**
Laridae: gulls, terns and skimmers	10	0	0	0	28	6	**44**
Ciconiidae: storks	3	0	10	0	6	1	**20**
Charadriidae: plovers	0	0	9	10	0	0	**19**
Accipitridae: diurnal birds of prey other than falcons	2	2	6	0	0	1	**11**
Gruidae: cranes	0	0	0	0	10	0	**10**
Podicipedidae: grebes	0	7	0	0	2	0	**9**
Accipitridae: African fish eagles	1	0	0	0	0	0	**1**
Total	71	14	468	1490	845	1061	**3949**

4.8 Kenya Rift Valley flamingo population trends

Lake Oloiden whose salinity is dependent on the water levels in the adjacent Lake Naivasha is known to host both lesser and greater flamingos. Generally, the population of lesser flamingos in this lake varies greatly from 0 to above 1000 as seen on the graph below (Figure 4.8). In some years the lake hosted no flamingo at all during the counting exercise. The lesser flamingo population is seen to increase from year 1997 to 2001 at a constant rate. From 2002, the counts were inconsistent thus difficult to establish the trends. However, highest number of lesser flamingos was recorded in 2009. Greater flamingo population was always lower than lesser flamingos at each count except for years 1994 and 2005 when the greater flamingos numbers were higher in compared to lesser flamingos. The two species show an irregular pattern over the years they were counted.

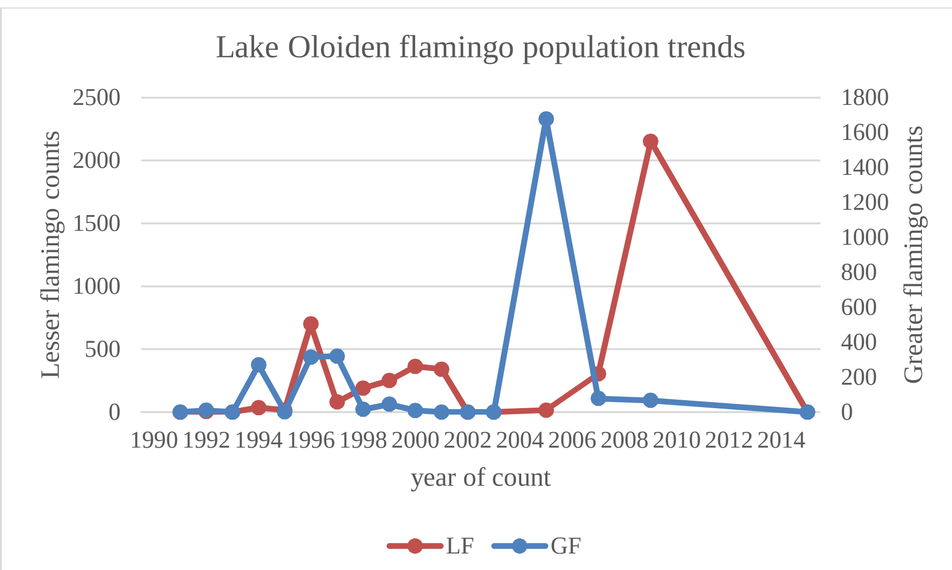


Figure 4. 8: Figure showing flamingo population trends in Lake Oloiden
Key

LF- Lesser Flamingo

GF- Greater Flamingo

Figure 4.9 below shows flamingo population trends for Lake Sonachi (Crater). Lake Sonachi (Crater) was not hosting any flamingo until the year 2000 when about 2700 lesser flamingos were counted at the lake. This sharp peak was followed by a sharp decline in the following year when no flamingo was counted. A significant rise was realized in 2003 but it was hard to predict the trend for subsequent years due to missing data. However, presence of lesser flamingos in this lake seems to be by chance as most of the time, no flamingos were counted. Despite lack of established trends, presence of lesser flamingos in this lake at such numbers is indicative of likely constant habitation of the lake by the lesser flamingos. Greater flamingos are rarely found in this lake. The highest numbers of greater flamingos ever reported are 2 in number.

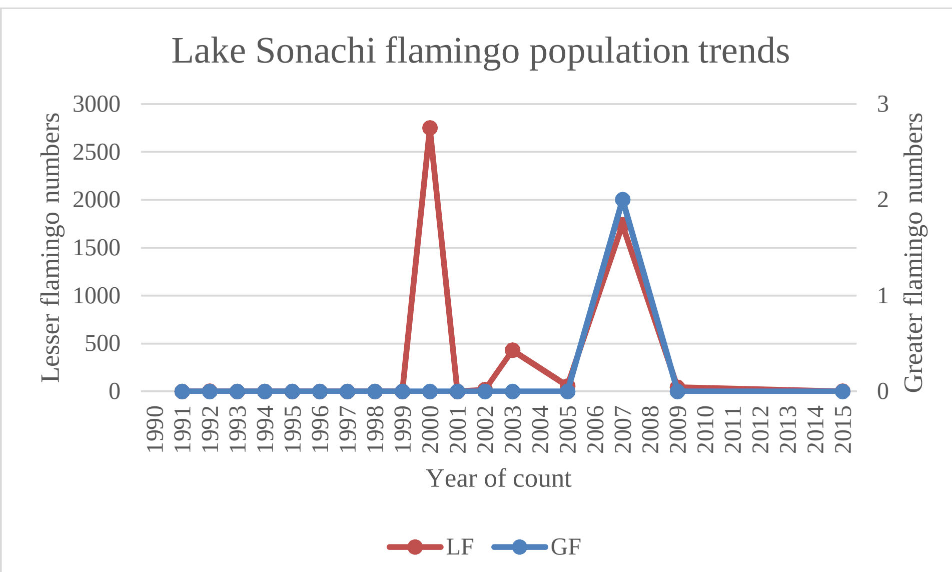


Figure 4. 9: Flamingo population trends in Lake Sonachi (Crater)
Key

LF- Lesser Flamingo

GF- Greater Flamingo

The population of greater flamingos in Lake Naivasha (figure 4.10) was higher than lesser flamingos over the years counted. The population of greater flamingos is greatly variable between years and there is no overall decline or increase in pattern. However, alternate rise and decline in numbers between years is evident between year 1991 and 1997. Lesser flamingos were rarely found in this lake during counting.

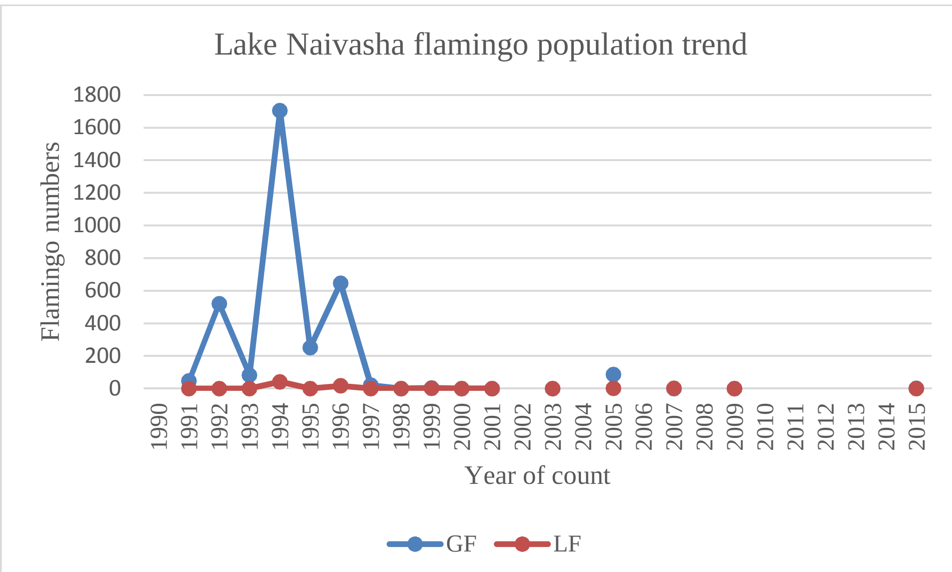


Figure 4. 5: Flamingo population patterns in Lake Naivasha

Key

GF- Greater Flamingo

LF- Lesser Flamingo

The population pattern for greater flamingos (Figure 4.11) in Lake Bogoria show alternate high and low numbers as seen from the year 1992 to 2001 when counts were consistent. From 2001, there is irregular pattern due to missing data although the numbers indicate a great decline as compared to the populations in the year 2001 and there is evidence of no steady pattern between years of count. Lesser flamingos are high in numbers compared to greater flamingos in Lake

Bogoria. There was a steady rise in lesser flamingo numbers from the year 1995 to 1999 followed by a sharp decline from the year 2000 as seen from the graph. Since then, it is evident that the numbers continue to dwindle. Little can be discussed from the year 2006 as the data is missing. Although the few years recorded indicate a general decline.

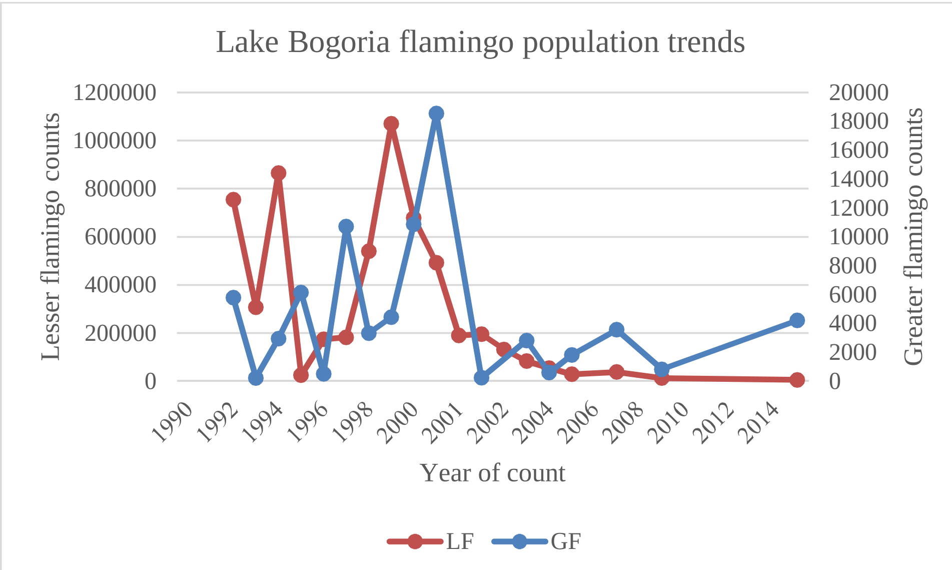


Figure 4. 6: Figure showing flamingo population trends in Lake Bogoria

Key

LF- Lesser Flamingo

GF- Greater Flamingo

The trend for lesser flamingos in L. Elementaita is highly variable (figure 4.12). However a general decline is evident from the year 2001 to 2015. For greater flamingos, a pattern of alternate highs and lows are evident between years of counts. The numbers for greater flamingos declined between the year 1997 and 2005. It is until 2006 that a steady increase is encountered. The low numbers in 2015 might be an indicator of future drop in numbers for the greater flamingo.

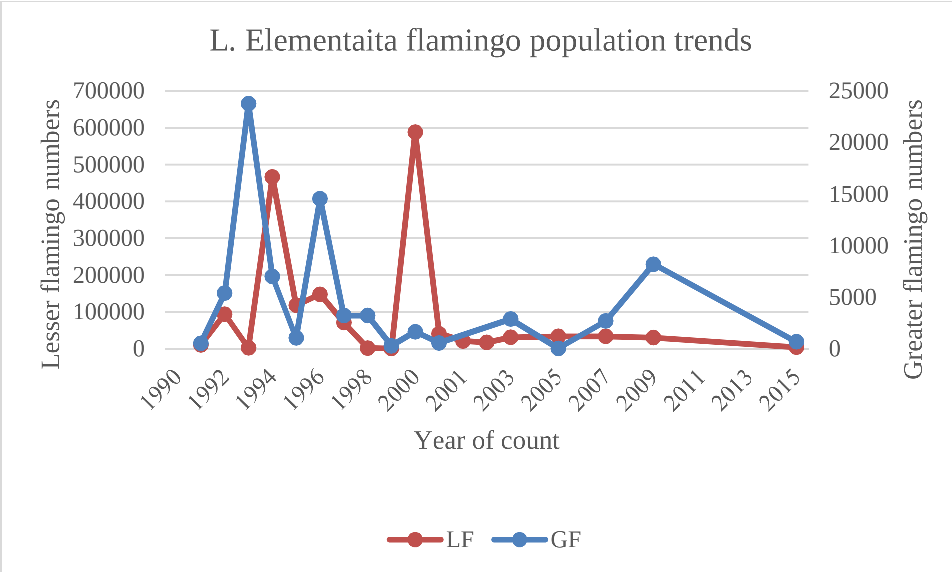


Figure 4. 7: Flamingo population trends in Lake Elementaita

Key

LF- Lesser Flamingo

GF- Greater Flamingo

Lake Magadi is not given much attention when it comes to annual flamingo counts as there is much data missing for several years. Lesser flamingo population peaked only in the year 1999 when the populations shoot from 25000 in 1998 to above 40000 in 1999. Since then, the lesser flamingo population in this lake are on a general decline although there is a lot of missing data from the year 2005. Greater flamingo population showed a peak in 1997 and since then, the numbers are declining.

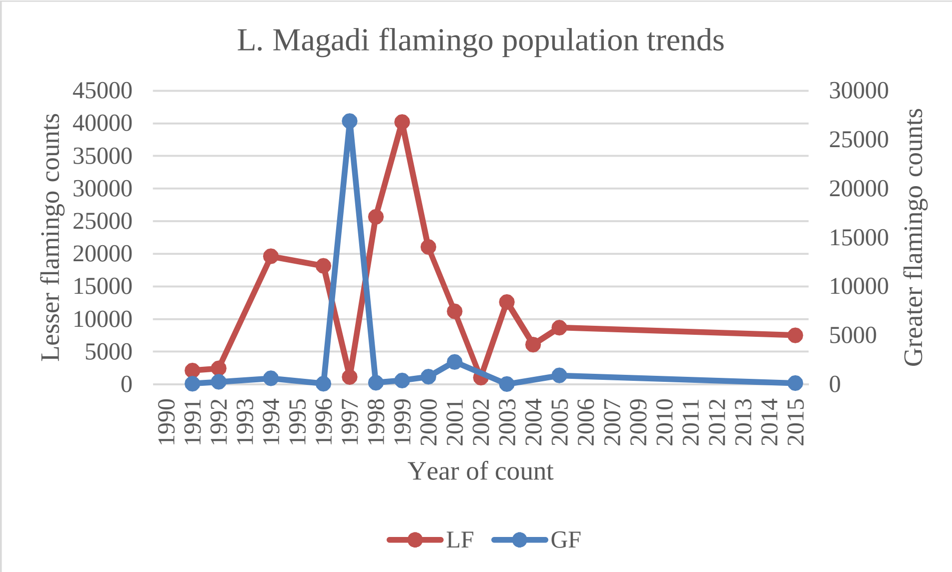


Figure 4. 8: Flamingo population trends in Lake Magadi

Key

LF- Lesser Flamingo

GF- Greater Flamingo

Lake Nakuru is known to host large numbers of flamingos as compared to other lakes. Most counts are recorded in this lake as compared to other lakes probably due to the large numbers of flamingos frequently hosted by the lake. It is in this lake that lesser flamingos about 1.5 million are recorded as seen on the graph (Figure 4:14) in July 1993 counts. However, the numbers are highly variable as no constant pattern between years is seen. Greater flamingo numbers are also higher in this lake as compared to other lakes. Greater flamingo population pattern is also not predictable as the numbers between years are highly variable. However, the 2008, 2009 and recent 2015 counts in both greater and lesser flamingos shows a declining trend.

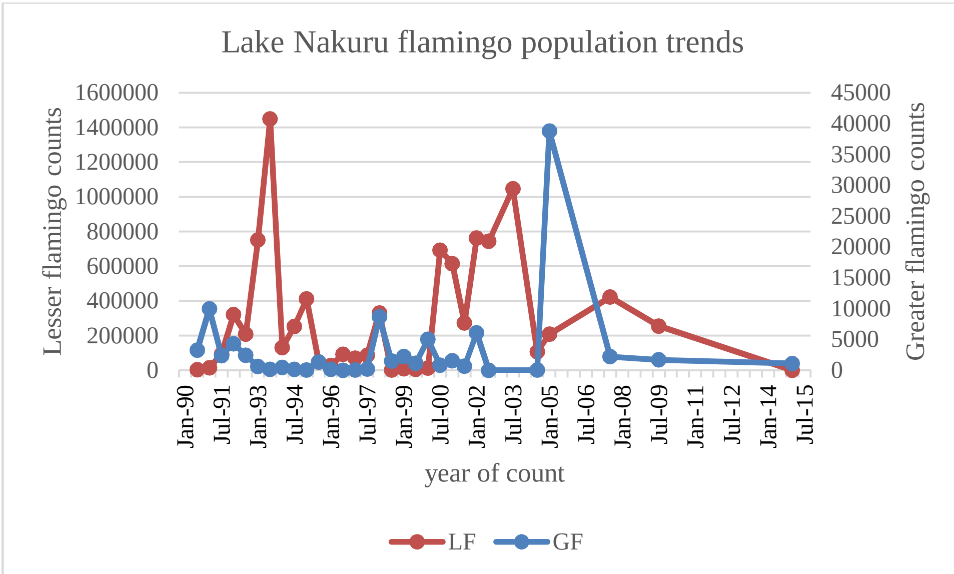


Figure 4. 9: Flamingo population trends in Lake Nakuru

Key

LF- Lesser Flamingo

GF- Greater Flamingo

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 DISCUSSION

Results from sediment metal element analysis showed that Manganese, cobalt, copper, zinc and chromium were present in all the six lakes. High concentrations of manganese above benchmark levels (631ppm, EPA,2007 benchmarks) were detected in Lake Bogoria (3676.7 ± 6652.3ppm) and Lake Elementaita (747.55 ± 510.95). Concentrations in Lake Bogoria may be due to erosion and natural leaching from rocks, soils and volcanic activity. High levels of manganese causes DNA damage, affect fetal development and chromosomal aberrations thus toxic to fetus. Copper, Zinc, Chromium and Arsenic were below the benchmark levels and Cadmium was not detected in any of the Lakes.The mean sediment concentrations (in ppm) dry weight ranged from 11.52-100.82 (Co), 1.865-8.9233 (Cu), 16.14-57.236 (Zn), 0.15667-0.295 (Cr), 2-6ppm (As). Cadmium findings in sediments were contrary to the study by Ochieng *et al*., 2007 and Tenai *et al*., 2015. Tenai *et al*., 2015 found traces of cadmium in Crater, lakes Elementaita, Nakuru and Oloiden whose mean concentration ranged from 0.0004673 – 0.08288ppm whereas Ochieng *et al*., 2007 found traces of cadmium ranging from 0.00005 – 0.0118ppm.All sites except hot spring area had significant levels of Nickel (Ni) with the (site 2) around Chebuluny Swamp having highest concentration of 100ppm followed by the site at entrance of Wasekes river (site 1) at northern part of the lake with the concentration of 50ppm, 20ppm near the water meter (site 3) and lastly 20ppm at site 4 which was the only site with flamingos. The high levels (38 ± 38.987ppm) may be attributed to natural geochemical processes since little anthropogenic activities take place around Lake Bogoria.

Lead was only detectable at one site in Lake Magadi (around the hot springs) at a concentration of 40ppm. Lake Oloiden, recorded highest level of lead among the six lakes with a mean concentration of 42 ppm which were above the benchmark level (36ppm). Lead levels in Lake Oloiden may be due to spillage from fresh water Lake Naivasha since a lot of anthropogenic activities especially flower farming occur around Lake Naivasha. The high Pb in Lake Nakuru may be emanating from the sewage treatment plant which drains directly into the lake. run-off from Nakuru town industries are also possible sources of high Pb in Lake Nakuru. These levels are toxic to aquatic organisms and bioaccumulation in fish is likely to occur thus hazardous to humans consuming fish from Lake Oloiden. Birds relying on the lake are also at greater risk of Lead (Pb) toxicity. Mercury (Hg) was not detectable in all sediment samples however it should not be ruled out since the available method used (XRF) could only detect elemental mercury and not the organic forms.

Arsenic metal element which is associated with volcanism was found in lakes Oloiden, Crater and Bogoria at a mean concentration of 4 ±5.477ppm, 6 ± 5.477ppm and 2 ± 4.472ppm respectively. These findings in Lake Nakuru are contradictory to those found by Franz et al., 2013. According to Franz *et al*., 2013, Lake Nakuru had Arsenic mean concentration of 6.1ppm while in this study no detectable levels were found in the lake. This may be due to dilution by rising water levels thus lowering the concentration below detection limits. The findings in Lake Bogoria were in agreement with those reported by Franz *et al*., 2013.

Dissolved metal concentrations in water were much lower compared to sediment samples and the mean concentrations (in ppm) ranged from 0.00433 – 0.0052 (Mn), 0.1742 – 2.3482 (Co), 0.04 (Cu), 0.05083 – 0.1526 (Zn), 0.7958 – 1.3918 (Cr) and 0.0015 – 0.0118 (Pb). Cadmium was not detected in any of the lakes. Cobalt (Co) was detected in Lake Magadi (2.3482 ± 0.98588ppm) and Lake Bogoria (0.1742 ±0.04707) at concentrations above the benchmark levels (0.023). Copper (Cu) was only detected in Lake Magadi water at a mean concentration of 0.04 ± 0.0141 which was above the threshold limit (0.003ppm). High levels of Zinc and Chromium were recorded in all the six lakes with lake Bogoria having the highest concentration of Zinc (0.1526 ± 0.21657). The levels in Bogoria were much higher than those reported by Franz *e*., 2013 whose concentrations ranged from <0.010 to 0.100ppm. The elevated levels of Zinc in aqueous samples of all the lakes point to the fact that, pollution due to anthropogenic activities may be contributing to the rising levels. However, a remote Lake Bogoria with such high levels of Zinc yet very little human activities take place around the lake need further examination to establish the real source of the high zinc levels. The trace elements Cu, Cd and Pb findings in lakes Bogoria and Nakuru are in agreement with those reported by Kerrich *et al*., 2002 and Owen *et al*., 2008 where the values found were below the detectable limits of 0.005ppm. This finding indicates no anthropogenic influence on these metals in the two lakes.

In this study, fluoride concentration was recorded in all the six lakes. In Lake Nakuru, no fluoride was detected at the two rivers inlet and sewage inlet. This implies that the two rivers and the sewage were not discharging detectable amounts of fluoride to the lake. This finding is contrary to earlier studies by Tenai, 2015 who found considerable amounts of fluoride discharge from rivers and sewage treatment plant. The levels found in Lake Bogoria and Nakuru i.e. 170.23 ± 0.81ppm and 33.11 ± 46.86 ppm respectively were contradictory to those reported by Schlueter, 1993 who reported 1060ppm in Lake Bogoria, Franz *et al*., 2013 who reported a range of 520 – 1370ppm in Lake Nakuru and 1000 – 1300ppm in Lake Bogoria and Tenai *et al*., 2015 who reported a mean of 247.9 ± 170.4ppm.

This difference may be due to the fact that Franz *et al*., 2013 carried out their study during the drought period when the element was highly concentrated as compared to this study which was carried out just after the heavy rains and mineral dilution could have occurred. This does not imply that fluoride levels are at decline. For Lake Oloiden, the findings are in agreement with those found by Tenai *et al*., 2015 and these low levels are attributable to the dilution by fresh water spilling from Lake Naivasha. The levels of fluoride in both water and sediments were slightly higher than those reported by Tenai *et al*., 2015 in Crater Lake and Lake Elementaita. Volcanic activity associated with geological processes is the main source of high fluoride levels in rift valley lakes. These levels are toxic to both aquatic organisms and humans when exposed either for a short or long periods. High levels of fluoride in an organism causes reduced immunity, erythrocyte deformities, hormonal effects, repeated abortions and still births, male sterility neuorological effects (Johansen 2013)

The great rises in water levels in Lake Nakuru and Bogoria have a great impact on water quality factors. Dilution by rising levels lowers the lake's alkalinity which in turn interferes with the growth of green algae, the food for lesser flamingos. These unfavorable conditions are the reason for reported migration of flamingos to new habitats such as Lake Simbi in Southern Nyanza and Odanga swamp. These new habitats need to be studied to establish their characteristics that favor flamingo habitation.

Water birds distribution in Kenya Rift valley lakes is not influenced by the concentration of heavy metals in both water and sediments. Other factors may be associated with water birds distribution. This is the first study to test the association between water birds distribution and metal elements concentration.

Flamingo population trends based on annual counts show massive variation. Lake Oloiden whose salinity is dependent on lake Naivasha water levels shows a great variation in flamingo population patterns with some years recording zero count (figure 4:10). Presence of flamingos in this lake is dependent on water quality factors especially water salinity levels. During zero counts, it is likely that during that time, the lake salinity was too low to support flamingo food thus no flamingo at the lake. Increased number of flamingos at this lake as seen in year 2005 for greater flamingos and 2009 for lesser flamingos might have been as a result of increased salinity thus enough food to support such numbers. This fact was evident during the study in January 2016 whereby the lake water was tending towards freshness and no flamingos were sighted.

Lake Sonachi was not hosting any flamingo from 1990 to 1998. It was not until 1999 that 2750 lesser flamingos inhabited the lake. This may be as a result of flamingos seeking alternative habitats due to degradation of their usual Lakes Nakuru, Bogoria and Magadi habitats.

Fresh water Lake Naivasha had greater flamingos than lesser flamingos and this may be due to the fact that greater flamingos depend on more varieties of food that can be found in fresh water lake such as shrimps, crustaceans and mollusks.

5.2 CONCLUSION

a) The selected Rift Valley alkaline Lakes are heavily polluted by metal elements from anthropogenic activities and natural processes. These levels are toxic to biological organisms that rely on these lakes.

b) Water birds distribution in Kenya Rift Valley lakes is not influenced by the levels of metal elements in the lakes. Other factors other than metals may be associated with water birds distribution.

c) The population trends of both lesser and greater flamingos in Kenya Rift valley lakes are highly variable making future projections of their populations difficult.

5.3 RECOMMENDATIONS

a) More studies on the association between metal element concentration and water birds distribution is needed.

b) There is need for continuous investigations for the purposes of ecosystem health monitoring.

c) The sewage treatment plant in Lake Nakuru Park needs to be relocated from the park since high Pb levels are harmful to the animals in the park and Lake

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APPENDICES

Appendix1: Concentration of fluoride in sediment samples from lakes Elementaita, Bogoria, Oloiden, Crater, Magadi and Nakuru.

Site	Reading 1 "(RMvs)	Reading 2 (RMvs)	Average (RMvs)	F-conc (ppm)
Elmnt 1	26.3	25.5	25.9	27.05
Elmnt 2	14.6	15.2	14.9	38.724
Elmnt 3	19.8	19.8	19.8	33.28
Elmnt 4	35.9	48.1	42	12.86
Elmnt 5	32.2	28.6	30.4	22.76
Nkrnjr R.	137.3	129.9	133.6	ND
Nkra.c.w	98.9	103.2	101.05	ND
Nkr W.C.K	109.9	97.8	103.85	ND
Nkrswge	105.9	96.9	101.4	ND
NkrMkr R.	88.7	91.4	90.05	ND
Mgd SL 1	79.2	82	80.6	ND
Mgdsprng	53.8	58.4	56.1	3.12
Mgd f. c.w	65.8	55.9	60.85	0.4
MgdM.g. b	58.2	50.3	54.25	4.26
Mgd SL 2	40.2	43.3	41.75	13.06
Mgd WL	67.9	66.3	67.1	ND
Crater 1	8.9	24.6	33.5	19.95
Crater 2	22.3	8.5	15.4	38.06
Crater 3	7.7	12.2	9.95	44.32
Crater 4	32.3	34	33.35	20.08

Crater 5	33.3	21.5	27.4	25.59
Oloiden 1	104.6	97.8	101.2	ND
Oloiden 2	80.4	72.5	76.45	ND
Oloiden 3	87.9	115.4	101.65	ND
Oloiden 4	89.5	50.9	70.2	ND
Oloiden 5	102.6	102.7	102.65	ND
Bogoria 1	90.6	123.2	106.9	ND
Bogoria 2	46.5	46.2	46.35	9.6
Bogoria 3	66.6	77.6	72.1	ND
Bogoria 4	109.7	98.1	103.9	ND
Bogoria 5	45.4	46.2	45.8	10

Appendix 2: Fluoride concentration for water samples

Site	**Reading 1 (RMVs)**	**Reading 2 (RMvs)**	**Average (RMvs)**	**F-conc (ppm)**
MgdSl 1	-52.6	-52.4	-52.5	118.51
Mgdspng	-87.8	-86.7	-87.25	188.36
Mgd SL2	-98.4	-99.3	-98.85	215.01
MgdWl	-98	-98.6	-98.3	213.71
Mgdm.g.b	-66.4	-65.9	-66.15	144.16
Mgdf.c.w	-99.5	-99.1	-99.3	216.07
NkrNjr R.	84.3	92.5	88.4	ND
NkrMkr R.	67.6	67	67.3	ND
Nkr W.C.K	-18.6	-20.4	-19.5	66.04
Nkr sewage	52	52.6	52.3	ND
Nkra.c.w	-41.5	-41.5	-41.5	99.52

Elmnt 1	-63.7	-64.3	-64	139.97
Elmnt 2	-63.2	-63.7	-63.45	138.9
Elmnt 3	-63.3	-63.4	-63.35	138.71
Elmnt 4	-63.5	-63.6	-63.35	138.71
Elmnt 5	-63.4	-63.5	-63.45	138.9
Bogoria 1	-78.9	-79.1	-79	170.42
Bogoria 2	-79.4	-79.4	-79.4	171.27
Bogoria 3	-79	-79.2	-79.1	170.63
Bogoria 4	-78.5	-78.5	-78.5	169.36
Bogoria 5	-78.5	-78.6	-78.55	169.46
Oloiden 1	3.4	3.2	3.3	37.67
Oloiden 2	0.7	1.3	1	40.24
Oloiden 3	1.4	0.9	1.15	40.07
Oloiden 4	1.5	0.9	1.2	40.02
Oloiden 5	1.5	1.6	3.1	37.89
Crater 1	-32.5	-33.1	-32.8	85.56
Crater 2	-32.6	-32.8	-32.7	85.41
Crater 3	-33.1	-33	-33.05	85.95
Crater 4	-32.5	-30.4	-31.45	83.47
Crater 5	-32.3	-32.9	-32.6	85.25

Appendix 3: Metal element concentrations (ppm) in sediments from Lakes Nakuru, Bogoria, Magadi, Crater, Oloiden and Elementaita analyzed by Atomic Absorption Spectrophotometry

Ref. no.	**Mn**	**Co**	**Cu**	**Zn**	**Cd**	**Cr**
Naksa.c.w	175.62	8.64	2.32	32.38	ND	0.24
Naksswg	209.36	0.78	6.94	97.4	ND	0.26
Naks MKL	560.007	7.08	3.16	29.56	ND	0.26
Naks WCK	208.8	9.8	16.26	17.04	ND	0.08
Naksnjr r	477.8	477.8	12.62	109.8	ND	0.14
Mgd F.C.W	249.2	11.58	7.8	39.96	ND	0.06
Mgd SL 2	213.8	22.88	9.14	24.34	ND	0.24
Mgd M.G.B	401.8	10.86	7.06	21.28	ND	0.2
Mgd WL	117.44	8.58	6.04	21.68	ND	0.14
MgdSprn	276.2	8.5	8.1	23.72	ND	0.18
Mgd SL 1	241	6.72	15.4	27.5	ND	0.12
Oloiden 1	65.1	ND	1.58	16.12	ND	0.44
Oloiden 2	54.86	8.36	2	16.2	ND	0.18
0loiden 3	ND	13	ND	7.86	ND	ND
Oloiden 4	86.14	4.78	3.72	15.96	ND	0.5
oloiden 5	279.8	21.3	0.16	24.56	ND	0.06
Crater 1	163.4	31.94	4.8	11.62	ND	ND
Crater 5	129.3	11.3	10.42	22.68	ND	0.2
Crater 3	209.76	22.22	9.26	30.14	ND	0.18
Crater 4	146.24	47.9	10.72	25.04	ND	0.26
crater 2	180.8	22.38	11.16	21.2	ND	0.22
Bogoria 1	791.4	22.38	6.68	18.76	ND	0.3

Bogoria 2	15562	24.44	5.46	21.94	ND	0.26
Bogoria 4	1090	10.22	2.2	30.88	ND	0.18
Bogoria 3	758.6	ND	ND	104.6	ND	0.12
Bogoria 5	1480.6	9.86	1.38	96.6	ND	0.16
Elmt 1	498.4	21.22	ND	28	ND	0.3
Elmt 2	752.8	18.3	ND	11.42	ND	0.18
Elmt 3	906.2	5.28	36.34	21.78	ND	0.24
Elmt 4	99.74	ND	ND	16.84	ND	0.24
Elmt 5	37	15.5	ND	12.3	ND	0.16

Appendix 4: Metal element concentrations in water samples from Lakes Nakuru, Bogoria, Magadi, Crater, Oloiden and Elementaita analyzed by Atomic absorption spectrophotometry

Ref. No.	Mn	Co	Cu	Zn	Cd	Cr	Pb
Naksa.c.w	0.008	ND	ND	0.032	ND	0.71	0.002
Naksswg	0.004	ND	ND	0.029	ND	0.745	ND
NaksMklia	0.001	ND	ND	0.032	ND	0.798	0.001
NaksWck	ND	0.034	ND	0.032	ND	0.831	ND
NaksNjr R	ND	ND	ND	0.35	ND	0.895	ND
Mgd F.C.W	0.006	3.089	0.05	0.004	ND	0.914	0.014
Mgd SL2	0.003	3.063	ND	0.061	ND	1.048	0.014
Mgd M.G.B	0.002	1.808	ND	0.06	ND	1.29	0.01
Mgd WL	0.003	3.109	0.03	0.053	ND	1.346	0.014
MgdSpn area	0.008	2.383	ND	0.051	ND	1.329	0.007
Mgd SL1	0.006	0.637	ND	0.076	ND	1.416	ND
Oloiden 1	0.006	ND	ND	0.048	ND	1.327	ND

Oloiden 2	0.006	ND	ND	0.049	ND	1.332	ND
Oloiden 3	0.005	ND	ND	0.048	ND	1.352	ND
Oloiden 4	0.005	ND	ND	0.049	ND	1.327	ND
oloiden 5	0.005	ND	ND	0.05	ND	1.337	ND
Crater 1	0.005	ND	ND	0.051	ND	1.364	ND
crater 5	0.005	ND	ND	0.051	ND	1.362	ND
crater 3	0.005	ND	ND	0.051	ND	1.364	ND
crater 4	0.005	ND	ND	0.052	ND	1.378	ND
crater 2	0.004	ND	ND	0.051	ND	1.361	ND
bogoria 1	0.006	0.16	ND	0.54	ND	1.33	ND
bogoria 2	0.006	0.178	ND	0.054	ND	1.373	ND
bogoria 4	0.008	0.253	ND	0.057	ND	1.405	ND
bogoria 3	0.006	0.147	ND	0.055	ND	1.419	ND
bogoria 5	0.006	0.133	ND	0.057	ND	1.432	0.001
Elmt 1	0.005	ND	ND	0.055	ND	1.439	ND
Elmt 2	0.005	ND	ND	0.055	ND	1.426	ND
Elmt 3	0.005	ND	ND	0.055	ND	1.425	ND
Elmt 4	0.005	ND	ND	0.055	ND	1.413	ND
elmt 5	0.006	ND	ND	0.056	ND	0.413	ND

Appendix 5: January and July annual flamingo counts from 1990 to 2015 in Lakes Oloiden, Sonachi, Naivasha, Nakuru, Magadi, Elementaita and Bogoria.

	OLOIDEN		SONACHI		NAIVASHA		NAKURU		MAGADI		ELEMENTAITA		BOGORIA	
YEAR	GF	LF	GF	LF	GF	LF	GF	LF	GF	LF	GF	LF	GF	LF
[1]1990														
[7]1990							3239	4239						
[1]1991	0	0	0	0	46	0	9937	15102	63	2121	543	10463		
[7]1991							2395	93121						
[1]1992	10	4	0	1	520	0	4323	320300	237	2435	5393	94080	5786	754200
[7]1992							2413	208261						
[1]1993	0	0	0	0	82	0	612	750169			23772	2497	229	307139
[7]1993							172	1448507						
[1]1994	270	35	0	0	1705	41	450	130517	609	19614	7012	466648	2941	865254
[7]1994							142	253490						
[1]1995	2	15	0	0	250	0	36	411152			1058	118160	6143	24849
[7]1995							1350	46785						
[1]1996	315	700	0	0	646	17	128	26894	68	18140	14560	147978	516	174106
[7]1996							14	91152						
[1]1997	320	80	0	0	21	0	60	69447	26906	1119	3226	71197	10708	182348
[7]1997							215	86680						
[1]1998	15	190	0	0	0	0	8658	330747	170	25683	3218	1926	3322	539728
[7]1998							1480	1133						
[1]1999	45	250	0	0	4	1	2211	9073	395	40188	285	711	4437	1070095
[7]1999							1139	4671						
[1]2000	9	363	0	2750	0	0	5023	13407	773	21025	1657	588376	10875	678140
[7]2000							798	692325						
[1]2001	0	341	0	0	0	0	1540	614512	2287	11188	564	40982	18540	491972
2001[7]							644	272046				21000		190000
[1]2002	0	0	0	18			6043	761679		1000		17313	240	196119
[7]2002							0	743227						132315
[1]2003	0	0	0	430	0	0			17	12607	2876	31266	2825	83616

[7]2003								1046988						
[1]2004														
[7]2004							28	105933		6090			590	54835
[1]2005	1678	15	0	57	85	1	38754	208217	898	8696	45	33556	1815	29085
[7]2005														
[1]2006														
[7]2006														
[1]2007														
[7]2007	78	304	2	1740	0	1	2217	422341			2689	33768	3563	38218
[1]2008														
[7]2008														
[1]2009														
[7]2009	67	2153	0	43	0	0	1694	255294			8193	30194	823	12929
[1]2010														
[7]2010														
[1]2011														
[7]2011														
[1]2012														
[7]2012														
[1]2013														
[7]2013														
[1]2014														
[7]2014														
[1]2015	0	0	0	1	2	0	1092	430	119	7507	674	4332	4210	5613
[7]2015														

Appendix 6: Birds sighted at or around the lakes

Family	Lake Oloiden	Crater Lake	Lake Element	Lake Bogoria	Lake N	Lake Magadi	
Phoenicopteridae: flamingos		1		1400		476	**1877**
Scolopacidae: sandpipers and relatives		4	250	50	367	191	**862**
Recurvirostridae: stilts and avocets			3	24	69	357	**453**
Anatidae: ducks and geese			5	5	207	20	**237**
Pelecanidae: pelicans	15		53		52		**120**
Ardeidae: herons, egrets and bitterns	5		54	1	45	8	**113**
Threskiornithidae: ibises and spoonbills			78		24	1	**103**
Phalacrocoracidae: cormorants	35				35		**70**
Columbidae: pigeons and doves				20	39	5	**64**
Laridae: gulls, terns and skimmers	10				28	6	**44**
Meropidae: bee-eaters						43	**43**
Pycnonotidae: bulbuls		5		12	10	6	**33**
Corvidae: crows and allies					23		**23**
Sturnidae: starlings and oxpeckers					23		**23**
Ciconiidae: storks	3		10		6	1	**20**
Ploceidae: weavers, bishops and widowbirds					20		**20**
Charadriidae: plovers			9	10			**19**
Muscicapidae: chats, wheatears and Old World flycatchers					19		**19**
Passeridae: sparrow weavers, Old World sparrows and petronias						15	**15**
Coliidae: mousebirds				13			**13**
Accipitridae: diurnal birds of prey other	2	2	6			1	**11**

than falcons							
Gruidae: cranes					10		**10**
Numididae: guineafowl						9	**9**
Podicipedidae: grebes		7			2		**9**
Alaudidae: larks						5	**5**
Laniidae: shrikes					3		**3**
Dicruridae: drongos		1			2		**3**
Motacillidae: wagtails, longclaws and pipits					3		**3**
Musophagidae: turacos				2			**2**
Bucerotidae: hornbills				2			**2**
Malaconotidae: helmetshrikes, bushshrikes, tchagras and puffbacks					2		**2**
Cisticolidae: cisticolas and allies					2		**2**
Nectariniidae: sunbirds				2			**2**
Phasianidae				1			**1**
Coraciidae: rollers					1		**1**
Alcedinidae: kingfishers	1						**1**