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Ecological risk assessment of heavy metals and water bird distribution in rift valley lakes, Kenya

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The study was carried out in six Kenyan rift valley lakes, Nakuru, Magadi, Oloiden, Crater (Sonachi), Bogoria and Elementaita with the aim to determine the levels of heavy metals and other metal elements (Co, Mn, Zn, Cu, Cr, Cd, Pb, Ni, Hg and As) in water and sediment samples as well as assess its association with water bird distribution. High levels of Pb (42 ppm) above the Pb benchmark levels (36 ppm) as per EPA (2007) benchmarks were detected in Lake Oloiden sediments. Lakes Bogoria and Elementaita had high levels of Mn (3676.7 ± 6652.3 and 747.55 ± 510.95, respectively), also above the Mn benchmark levels (631 ppm), according to EPA (2007). The mean sediment concentrations for Zn, Pb, Ni, As and Hg varied significantly ($P<0.05$) among the six lakes. Apart from Zn, all other metals (Pb, Co, Mn, Cr, Cd, Fe and Cu) varied significantly in all water samples from the six selected lakes ($P<0.05$). A total of 15 water bird families were identified across the six lakes. The distribution of the 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 ($P>0.05$). It was concluded that metals concentration in Kenyan Rift Valley lakes has no significant influence on the distribution of water birds. High Mn levels in lakes Bogoria and Elementaita, and Pb in Oloiden may cause toxic effects to the aquatic life and humans as a result of bioaccumulation.

Key words: Ecotoxicology, heavy metals, water birds.

INTRODUCTION

Ecology is the scientific study of abundance, distributions and relations of organisms and their interaction with the environment (Begon et al., 2006). Heavy metals such as common toxic chemicals in the environment since they are naturally occurring and they are resistant to biodegradation (Reena et al., 2011). Trace metals like lead, mercury, chromium and cadmium are among the copper, zinc and iron play a biochemical role in the life processes of all aquatic plants and animals. They are therefore essential in trace amounts (Jakimska et al.

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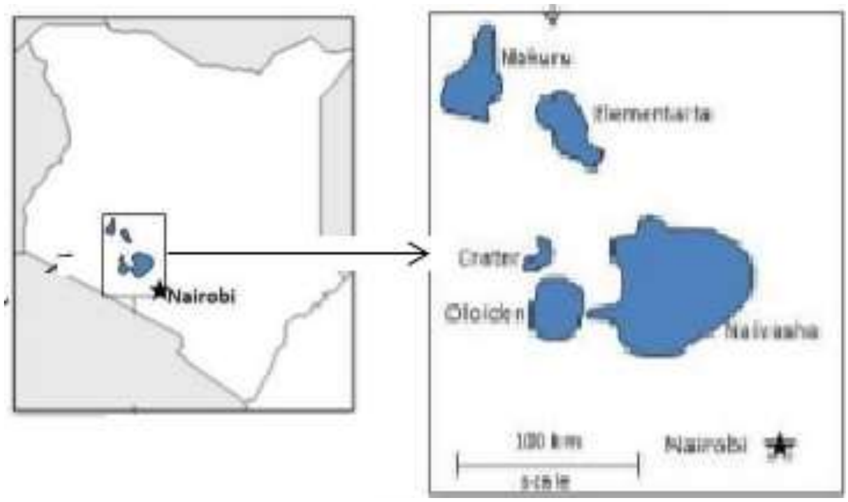

Figure 1. Map of Kenya showing rift valley lakes.

2011). However, high concentrations of these essential elements are toxic to aquatic life (Jakimska et al., 2011). The sources of metal elements in water bodies include, natural weathering, industrial wastes, sewage, surface run-off and agricultural effluents (Paul et al., 2012). Lake sediments form the final pathway of both anthropogenic and natural contaminants in the environment. Sediment quality is therefore a good indicator of pollution in the environment (Gavin and Marco, 2008; Samir and Ibrahim, 2008; Hahladakis et al., 2013).

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 (O'Doherty and Caro, 1999).

In recent years, there has been dynamic changes in water bird number in Kenyan Rift valley lakes and pollution levels due to heavy metals is among the incriminated factors suggested to be causing the change in water bird distribution (Motelin et al., 1995; Nelson et al., 1998; Motelin et al., 2000; Guynub, 2002; Ouko et al., 2016). A study on the association between water bird distribution and heavy metal concentration in the environment is needed. In this paper, baseline data on concentrations of Mn, Zn, Cu, Cd, Cr, Co, Ni, As, Pb and Hg in surface sediments and water samples from six Kenyan Rift Valley lakes (Nakuru, Magadi, Oloiden, Crater, Bogoria and Elementaita) is reported. Data on water bird families distribution across the six lakes and their association with heavy metal concentration is also given.

MATERIALS AND METHODS

Study area and sampling

The study was carried out in six alkaline lakes in Kenya (Rift Valley): Lakes Nakuru, Magadi, Oloiden, Crater, Bogoria and Elementaita (Figure 1). The study sites were chosen based on convenience and sample size purposively determined depending on site characteristics. Water and surface sediment samples were taken from five sites (SS) in Lake Nakuru, five SS in Lake Bogoria, five SS in Lake Oloiden and six SS in Lake Magadi (Table 1). In Lakes Elementaita and Crater, five replicate subsamples were taken from one site. Surface sediment (0-2 cm layer) samples were collected in zip lock plastic bags, properly labelled and transported at 4°C in cool boxes to the laboratory awaiting analysis. Water samples were taken in plastic capped containers and transported in cool boxes at 4°C to the laboratory.

Sample preparation

Water samples were prepared in duplicates by measuring 50 ml of water into a beaker, adding 2 ml of concentrated nitric acid and heating the contents on a hot plate to reduce the volume to 10 ml. After that, the mixture was filtered into a 50 ml volumetric flask and topped to the mark with demineralized water ready for analysis. Each sediment sample was well mixed and 20 g were weighed in aluminum foil papers and dried in an oven at 60°C overnight. The sample was then ground in a pulverizer and 2.5 g weighed into a 250 ml beaker before adding 20 ml of water to make sludge. Concentrated nitric acid (20 ml) 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 10 ml. This was then cooled and filtered into 50 ml volumetric flask, washed carefully with hot water and then topped to the mark ready for analysis. Known standards for each metal element were prepared from respective certified analytical standards at concentrations of 0.05, 0.1, 10 and 100 ppm. These known standards were read to generate calibration curves within the spectrophotometer before reading the samples. Standards were read after every reading of 5 samples to check the accuracy and precision of the machine and analytical process.

Instrumentation

Atomic absorption spectrophotometer (AAS) with an air/acetylene flame (Model SpectrAA-10) was used for analysis of Cd, Cr, Mn, Co, Zn and Cu in both water and sediment samples after preparation of appropriate calibration standards. Hg, Ni and As in

Table 1. The sites of sample collection from the six rift valley lakes.

Site	Magadi	Nakuru	Oloiden	Bogoria
1	South lagoon 1	Njoro R. Inlet	Kongoni landing bay	Wasekes R. Inlet
2	Spring area	Makalia R. Inlet	37m0195344	Chebuluny Swamp
3	South lagoon 2	WCK hostels	37m0195352	Water meter
4	Western lagoon	Sewage inlet		Flamingo area
5	Main gate barrier	After causeway	Kongoni	Hot springs
6	Factory causeway			

Table 2. Metal concentrations (ppm dry weight) in sediment samples in six Rift Valley lakes analyzed by atomic absorption spectrophotometry.

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 (EPA, 2007), bulk sediment toxicity benchmarks for benthic macroinvertebrates.

sediments were analyzed using a X-ray Fluorescence (XRF) analyzer (s1 TITAN RS 200). Pb in water samples was analyzed by AAS and Pb in sediment samples analyzed by XRF after the AAS Pb lamp becoming faulty.

Reagents

Heavy metal analytical standards were of analytical grade from Sigma - Aldrich Limited, TraceCERT® products. Water used was deionised water from ReAgent chemical suppliers, Cheshire, England, UK.

Glassware cleaning

Glass was cleaned with tap water, soap and brush, rinsed three times with 0.5 M perchloric acid before rinsing with distilled water three times. They were then dried in the oven at 60°C.

Water bird identification

Water birds along drive ways, were observed in each SS using binoculars and identified using a bird guide book (Zimmerman et al., 1999) and identified with help of an expert ornithologist from the National Museums of Kenya (NMK).

Data obtained was entered into Microsoft Excel® spreadsheet, 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 analyze the variation between and within the lakes Chi - square test (Appendix 4) was used to test the association between metals concentration and water bird distribution among the lakes.

RESULTS AND DISCUSSION

The mean concentrations of heavy metals Mn, Co, Cu, Zn, Cd, Cr, Pb, Hg, Ni and As analyzed in sediments and water samples from the six Rift valley lakes are showed in Tables 2, 3, 4, Appendix 1 and Appendix 2. Lake Bogoria recorded the highest Mn mean sediment concentrations of 3676 ppm; Lake Nakuru gave highest mean sediment concentrations of Co (100 ppm) and Lake Oloiden recorded highest mean concentrations of Pb (42 ppm) in sediments. The mean sediment levels of Mn in Lake Bogoria are within the ranges obtained by Ochieng et al. (2007) who obtained Mn mean sediment concentration of 3947 ± 121 ppm. The mean sediment concentrations for Cu, Zn, As and Cr were very low in all the six lakes (Table 2 to 4). Cd and Hg were not detectable in sediment samples from all the six lakes. The results on Cd concentrations in sediments differ from those obtained by Tenai (2015) who found traces of Cd (0.0004 to 0.076 ppm) in Lakes Crater, Elementaita, Nakuru and Oloiden. Ochieng et al. (2007) also obtained high levels of Cd (1.18 ppm) in sediment from Lake Elementaita. Cd was also not detectable in water samples from all the six lakes. This was in agreement with the results obtained by Tenai (2015) but contrary to those obtained by Ochieng et al. (2007) who recorded traces of Cd levels in water samples (2.0 to 5.0

Table 3. Metal concentrations (ppm dry weight) in sediment samples in six rift valley lakes analyzed by X-ray fluorescence.

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 (EPA, 2007), bulk sediment toxicity benchmarks for benthic macroinvertebrates; N, Number of samples.

Table 4. Dissolved metal concentrations (ppm) in water samples of the six rift valley lakes analyzed by atomic absorption spectrophotometry.

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 (EPA, 2007) bulk sediment toxicity benchmarks for benthic macroinvertebrates; ND, not detected; n, Number of samples.

µg/L) in Lake Baringo, (5.0 to 41.0 µg/L) in Lake Bogoria Bogoria (1.3918 ppm), Crater (1.3658 ppm) and Oloiden (3.0 to 43.0 µg/L) in Lake Nakuru and (3.0 to 25.1 µg/L) in Lake Elementaita. Dilution as a result of rising water levels in Kenyan Rift Valley Lakes may be responsible for undetected Cd. The mean sediment concentrations for Zn, Pb, Ni, As and Hg varied significantly ($P<0.05$) among the six lakes. Concentrations of Mn in Lake Bogoria may be attributed to natural leaching and erosion from rocks, volcanic activity and soils (Stokes et al., 1988) since the Lake is remote from anthropogenic activities. These high levels is a threat to biological lives that depend on the lake especially water birds. Elevated levels of Mn affect fetal development, causes DNA damage and chromosomal aberrations thus toxic to embryo (ATSDR, 2000). The levels of Co in Lake Nakuru may be attributed to the increased industrial activities around the lake. Spillway from fresh water Lake Naivasha is the likely source of Pb levels in Lake Oloiden since a lot of anthropogenic activities especially flower farming occur around Lake Naivasha. Surface run-offs from these farms are a good source of Pb in the lake. Birds depending on the lake are also at risk of Pb toxicity.

In water samples, high mean concentrations of Cr and Zn is above the threshold limits (0.011 and 0.036 ppm), respectively, according to EPA (2007) limit, were recorded in all the six lakes with highest Cr levels in (1.335 ppm) Table 3. These levels are much higher compared to those obtained by Ochieng et al. (2007) who obtained a maximum of 0.188 ppm in Lake Nakuru but lower than ranges (10 to 280 ppm) recorded by Nelson et al. (1998) in Lake Nakuru sediments. Highest Zn levels were recorded in Lake Bogoria (0.1526 ppm) (Table 3). Lake Magadi water samples had high levels of both Co (2.3482 ppm) and Cu (0.04 ppm) which were above the benchmark levels given by EPA (2007) limits (Table 3). Lake Bogoria also had high Co levels in water samples (0.1742 ppm). Mn levels were low in water samples from all the six lakes. Apart from Zn, all other metal elements (Pb, Co, Mn, Cr, Cd, Fe and Cu) varied significantly ($P<0.05$) in water samples among the six lakes. The noted high levels of metal elements in water columns from the lakes is a major concern since these lakes support many water birds, wild animals, fish among other biological organisms.

A total of 15 water bird families were identified across the six lakes (Table 5, Appendix 3). Phoenicopteridae family, which comprises flamingos, was the most abundant with an estimate of 1877 lesser flamingos (*Phoeniconias minor*), followed by Scolopacidae (862) and Recurvirstridae (453) families. The distribution of water bird families for lakes Nakuru, Magadi, Elementaita, Oloiden, Bogoria and Crater were11, 9, 9, 7, 6 and 4 respectively. African fish eagle of the family Accipitridae

Table 2. Number of water bird families identified at the six rift valley lakes.

Family	Lake Nakuru	Lake Magadi	Lake Oloiden	Crater Lake	Lake Bogoria	Lake Elementaita	Totals
Phoenicopteridae: Flamingos		476		1	1400		**1877**
Scolopacidae: Sandpipers and relatives	367	191		4	50	250	**862**
Recurvirostridae: Stilts and avocets	69	357			24	3	**453**
Anatidae: Ducks and geese	207	20			5	5	**237**
Pelecanidae: Pelicans	52		15			53	**120**
Ardeidae: Herons, Egrets and bitterns	45	8	5		1	54	**113**
Threskiornithidae: Ibises and spoonbills	24	1				78	**103**
Phalacrocoracidae: Cormorants	35		35				**70**
Laridae: Gulls, terns and skimmers	28	6	10				**44**
Ciconiidae: Storks	6	1	3			10	**20**
Charadriidae: Plovers					10	9	**19**
Accipitridae: Diurnal birds of prey other than falcons		1	2	2		6	**11**
Gruidae: Cranes	10						**10**
Podicipedidae: Grebes	2			7			**9**
Accipitridae: African fish eagles			1				**1**
Total	845	1061	71	14	1490	468	**3949**

was sighted at Lake Oloiden.

The test of association between mean heavy metal concentrations and water bird families distribution in the six lakes was performed using Chi-square test in Statistical Package for the Social Sciences (SPSS) version 24. There was no significant influence (P>0.05) (Appendix 4) of heavy metals on water bird distribution in all the lakes. This implies that other factors different from heavy metal concentrations affect the ever changing distribution of water birds in Kenya Rift Valley lakes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Appendix 1: 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 2: 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 3 : Table showing water bird families identified at the Lakes.

Family	Lake Oloiden	Crater Lake	Lake Elementaita	Lake Bogoria	Lake Nakuru	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
Laridae: gulls, terns and skimmers	10				28	6	44
Ciconiidae: storks	3		10		6	1	20
Charadriidae: plovers			9	10			19
Accipitridae: diurnal birds of prey other than falcons	2	2	6			1	11
Gruidae: cranes					10		10
Podicipedidae: grebes		7			2		9
Accipitridae: African fish eagles	1						1
Total	71	14	468	1490	845	1061	3949

Appendix 4: Computation table for metal concentrations in six Kenyan rift valley lakes for chi-square test.

Ref. no.	Mn	Co	Cu	Zn	Cd	Cr	
Naks a.c.w	175.62	8.64	2.32	32.38	ND	0.24	
Naks swg	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	
Naks njr r	477.8	477.8	12.62	109.8	ND	0.14	
Nakuru	**1631.587**	**504.1**	**41.3**	**286.18**		**0.98**	
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	
Mgd Sprn	276.2	8.5	8.1	23.72	ND	0.18	
Mgd SL 1	241	6.72	15.4	27.5	ND	0.12	
Magadi	**1499.44**	**69.12**	**53.54**	**158.48**		**0.94**	
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	
Oloiden	**485.9**	**47.44**	**7.46**	**80.7**		**1.18**	
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	
Crater	**829.5**	**135.74**	**46.36**	**110.68**		**0.86**	
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	
Bogoria	**19682.6**	**66.9**	**15.72**	**272.78**		**1.02**	
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	
Elementaita	**2294.14**	**60.3**	**36.34**	**90.34**		**1.12**	
Ref. No.	Mn	Co	Cu	Zn	Cd	Cr	
Nakuru	1631.587	504.1	41.3	286.18		0.98	
Magadi	1499.44	69.12	53.54	158.48		0.94	
Oloiden	485.9	47.44	7.46	80.7		1.18	
Crater	829.5	135.74	46.36	110.68		0.86	
Bogoria	19682.6	66.9	15.72	272.78		1.02	
Elementaita	2294.14	60.3	36.34	90.34		1.12	
Ref. No.	**Mn**	**Co**	**Cu**	**Zn**	**Cd**	**Cr**	**Pb**
Naks A.C.W	0.008	ND	ND	0.032	ND	0.71	0.002
Naks Swg	0.004	ND	ND	0.029	ND	0.745	ND
Naks Mklia	0.001	ND	ND	0.032	ND	0.798	0.001
Naks Wck	ND	0.034	ND	0.032	ND	0.831	ND
Naks Njr R	ND	ND	ND	0.35	ND	0.895	ND
Nakuru	**0.013**	**0.034**	**0**	**0.475**	**0**	**3.979**	**0.003**

Appendix 4: Contd.

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
Mgd Spn 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
Magadi	**0.028**	**14.089**	**0.08**	**0.305**	**0**	**7.343**	**0.059**
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
Oloiden	**0.027**	**0**	**0**	**0.244**	**0**	**6.675**	**0**
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
Crater	**0.024**	**0**	**0**	**0.256**	**0**	**6.829**	**0**
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
Bogoria	**0.032**	**0.871**	**0**	**0.763**	**0**	**6.959**	**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
Elementaita	**0.026**	**0**	**0**	**0.276**	**0**	**6.116**	**0**

Chi-square tests

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-square	12.000[a]	10	0.285
Likelihood ratio	10.411	10	0.405
Linear-by-linear association	0.585	1	0.444
N of valid cases	6		

[a]18 cells (100.0%) have expected count less than 5. The minimum expected count is 0.17.

Metal element concentrations in water samples from lakes Nakuru, Bogoria, Magadi, Crater, Oloiden and Elementaita analyzed by atomic absorption spectrophotometry

Association between Mn in water samples and bird families identified at the Lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	0.263	0.458	0.169
Scolopacidae: Sandpipers and relatives	0.224	0.664	0.135
Recurvirostridae: Stilts and avocets	0.242	0.540	0.838
Anatidae: Ducks and geese	0.263	0.385	0.045
Pelecanidae: Pelicans	0.263	0.458	0.147
Ardeidae: herons, Egrets and bitterns	0.224	0.664	0.200
Threskiornithidae: Ibises and spoonbills	0.263	0.458	0.646
Phalacrocoracidae: Cormorants	0.306	0.177	0.179
Laridae: Gulls, terns and skimmers	0.263	0.458	0.059
Ciconiidae: Storks	0.242	0.540	0.356
Charadriidae: Plovers	0.285	0.405	0.265
Accipitridae: Diurnal birds of prey other than falcons	0.263	0.385	0.732
Gruidae: Cranes	0.306	0.368	0.042
Podicipedidae: Grebes	0.285	0.408	0.444
Accipitridae: African fish eagles			

Association between Co in water samples and bird families identified at the Lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	0.178	0.270	0.653
Scolopacidae: Sandpipers and relatives	0.263	0.4580.	0.756
Recurvirostridae: Stilts and avocets	0.116	0.246	0.028
Anatidae: Ducks and geese	0.122	0.206	0.775
Pelecanidae: Pelicans	0.469	0.502	0.364
Ardeidae: Herons, egrets and bitterns	0.263	0.458	0.585
Threskiornithidae: Ibises and spoonbills	0.178	0.270	0.542
Phalacrocoracidae: Cormorants	0.392	0.282	0.450
Laridae: Gulls, terns and skimmers	0.178	0.270	0.860
Ciconiidae: Storks	0.301	0.435	0.481
Charadriidae: Plovers	0.321	0.360	0.535
Accipitridae: Diurnal birds of prey other than falcons	0.213	0.206	0.636
Gruidae: Cranes	0.112	0.144	0.635
Podicipedidae: Grebes	0.321	0.360	0.531
Accipitridae: African fish eagles			

Association between Cu in water samples and bird families identified at the lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: flamingos	0.112	0.144	0.752
Scolopacidae: sandpipers and relatives	0.306	0.368	0.729
Recurvirostridae: stilts and avocets	0.199	0.248	0.0.028
Anatidae: ducks and geese	0.112	0.144	0.795
Pelecanidae: pelicans	0.753	0.662	0.396
Ardeidae: herons, egrets and bitterns	0.306	0.368	0.622
Threskiornithidae: ibises and spoonbills	0.112	0.144	0.571
Phalacrocoracidae: cormorants	0.439	0.341	0.480
Laridae: gulls, terns and skimmers	0.112	0.144	0.894
Ciconiidae: storks	0.199	0.248	0.521
Charadriidae: plovers	0.741	0.635	0.480
Accipitridae: diurnal birds of prey other than falcons	0.112	0.144	0.682
Gruidae: cranes	0.624	0.526	0.655
Podicipedidae: grebes	0.741	0.635	0.559
Accipitridae: African fish eagles			

Association between Zn in water samples and bird families identified at the lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	0.263	0.458	0.057
Scolopacidae: Sandpipers and relatives	0.224	0.664	0.911
Recurvirostridae: Stilts and avocets	0.242	0.540	0.823
Anatidae: Ducks and geese	0.263	0.385	0.630
Pelecanidae: Pelicans	0.263	0.458	0.772
Ardeidae: Herons, egrets and bitterns	0.224	0.664	0.786
Threskiornithidae: Ibises and spoonbills	0.263	0.458	0.643
Phalacrocoracidae: Cormorants	0.306	0.177	0.818
Laridae: Gulls, terns and skimmers	0.263	0.458	0.909
Ciconiidae: Storks	0.242	0.540	0.549
Charadriidae: Plovers	0.285	0.405	0.214
Accipitridae: Diurnal birds of prey other than falcons	0.263	0.385	0.202
Gruidae: Cranes	0.306	0.368	0.633
Podicipedidae: Grebes	0.285	0.405	0.564
Accipitridae: African fish eagles			

Metal element concentrations (ppm) in sediments from lakes Nakuru, Bogoria, Magadi, Crater, Oloiden and Elementaita analyzed by atomic absorption spectrophotometry

Association between Mn concentrations (PPM) in sediments and bird families identified at the lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	0.263	0.458	0.035
Scolopacidae: Sandpipers and relatives	0.224	0.664	0.592
Recurvirostridae: Stilts and avocets	0.242	0.540	0.713
Anatidae: Ducks and geese	0.263	0.385	0.682
Pelecanidae: Pelicans	0.263	0.458	0.468
Ardeidae: Herons, egrets and bitterns	0.224	0.664	0.511
Threskiornithidae: Ibises and spoonbills	0.263	0.458	0.656
Phalacrocoracidae: Cormorants	0.306	0.177	0.441
Laridae: Gulls, terns and skimmers	0.263	0.458	0.465
Ciconiidae: Storks	0.242	0.540	0.434
Charadriidae: Plovers	0.285	0.405	0.105
Accipitridae: Diurnal birds of prey other than falcons	0.263	0.385	0.414
Gruidae: Cranes	0.306	0.368	0.686
Podicipedidae: Grebes	0.285	0.405	0.517
Accipitridae: African fish eagles			

Association between Co concentrations (PPM) in sediments and bird families identified at the lakes.

Family	Asymp0. Sig0. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	0.263	0.458	0.505
Scolopacidae: Sandpipers and relatives	0.224	0.664	0.129
Recurvirostridae: Stilts and avocets	0.242	0.540	0.922
Anatidae: Ducks and geese	0.263	0.385	0.029
Pelecanidae: Pelicans	0.263	0.458	0.225
Ardeidae: Herons, egrets and bitterns	0.224	0.664	0.288
Threskiornithidae: Ibises and spoonbills	0.263	0.458	0.891
Phalacrocoracidae: Cormorants	0.306	0.177	0.210
Laridae: Gulls, terns and skimmers	0.263	0.458	0.049
Ciconiidae: Storks	0.242	0.540	0.572
Charadriidae: Plovers	0.285	0.405	0.416
Accipitridae: Diurnal birds of prey other than falcons	0.263	0.385	0.352
Gruidae: Cranes	0.306	0.368	0.028
Podicipedidae: Grebes	0.285	0.405	0.570
Accipitridae: African fish eagles			

Association between Cu concentrations (PPM) in sediments and bird families identified at the lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	.263	.458	504
Scolopacidae: Sandpipers and relatives	.224	.664	275
Recurvirostridae: Stilts and avocets	.242	.540	198
Anatidae: Ducks and geese	.263	.385	.557
Pelecanidae: Pelicans	.263	.458	.870
Ardeidae: Herons, egrets and bitterns	.224	.664	.592
Threskiornithidae: Ibises and spoonbills	.263	.458	.731
Phalacrocoracidae: Cormorants	.306	.177	.384
Laridae: Gulls, terns and skimmers	.263	.458	.856
Ciconiidae: Storks	.242	.540	.911
Charadriidae: Plovers	.285	.405	.446
Accipitridae: Diurnal birds of prey other than falcons	.263	.385	.901
Gruidae: Cranes	.306	.368	.634
Podicipedidae: Grebes	.285	.405	.350
Accipitridae: African fish eagles			

Association between Zn concentrations (PPM) in sediments and bird families identified at the lakes.

Family	**Asymp. Sig. (2-sided)**	**Likelihood ratio**	**Linear by linear association**
Phoenicopteridae: Flamingos	0.263	0.458	0.211
Scolopacidae: Sandpipers and relatives	0.224	0.664	0.355
Recurvirostridae: Stilts and avocets	0.242	0.540	0.789
Anatidae: Ducks and geese	0.263	0.385	0.142
Pelecanidae: Pelicans	0.263	0.458	0.865
Ardeidae: Herons, egrets and bitterns	0.224	0.664	0.858
Threskiornithidae: Ibises and spoonbills	0.263	0.458	0.631
Phalacrocoracidae: Cormorants	0.306	0.177	0.749
Laridae: Gulls, terns and skimmers	0.263	0.458	0.275
Ciconiidae: Storks	0.242	0.540	0.704
Charadriidae: Plovers	0.285	0.405	0.708
Accipitridae: Diurnal birds of prey other than falcons	0.263	0.385	0.101
Gruidae: Cranes	0.306	0.368	0.152
Podicipedidae: Grebes	0.285	0.405	0.792
Accipitridae: African fish eagles			

Association between Cr concentrations (PPM) in sediments and bird families identified at the lakes.

Family	Asymp. Sig. (2-sided)	Likelihood ratio	Linear by linear association
Phoenicopteridae: Flamingos	.263	.458	.830
Scolopacidae: Sandpipers and relatives	.224	.664	.945
Recurvirostridae: Stilts and avocets	.242	.540	.424
Anatidae: Ducks and geese	.263	.385	.692
Pelecanidae: Pelicans	.263	.458	.376
Ardeidae: Herons, egrets and bitterns	.224	.664	.514
Threskiornithidae: Ibises and spoonbills	.263	.458	.388
Phalacrocoracidae: Cormorants	.306	.177	.351
Laridae: Gulls, terns and skimmers	.263	.458	.959
Ciconiidae: Storks	.242	.540	.242
Charadriidae: Plovers	.285	.405	.456
Accipitridae: Diurnal birds of prey other than falcons	.263	.385	.342
Gruidae: Cranes	.306	.368	.733
Podicipedidae: Grebes	.285	.405	.113
Accipitridae: African fish eagles			