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# Assessment of Heavy Metals Contamination in Lake Elementaita Drainage Basin, Kenya

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## ABSTRACT

The future of Lake Elementaita, Kenya, hangs in the balance between environmental conservation and exploitation of the catchment resources for agricultural and industrial development. In the recent past the Lake has experienced water quality deterioration that is likely to lead to adverse ecological effects of the lake biodiversity. This study aimed at determining the impact of human activities in the catchment on contamination of heavy metals namely; cadmium, copper, lead and zinc. We collected water, sediments and soil samples from seven sites in the lake drainage basin to determine the extent of physico-chemical parameters and heavy metals concentrations. Samples for heavy metals determination were digested using aqua regia solution followed by perchloric acid and analysed by Atomic Absorption Spectrometer, while physico-chemical parameters were analysed using portable meters. Water pH ranged from 6.94 to 10.84, TDS from 0.07 g/L to 4.21 g/L, TSS from 0.01 g/L to 0.07 g/L, while electrical conductivity ranged from 0.14 mS/cm to 8.40 mS/cm. Heavy metals concentrations in water ranged from 0.04 mg/L to 3.14 mg/L, whereas the levels in sediments ranged from bdl to 134 mg/kg and from 2.78 mg/kg to 86.95 mg/kg in soil samples. Except for zinc, the levels of the rest of the metals in water were above WHO recommended limits for drinking water suggesting that the water is not safe for life. The results revealed that human activities are contributing to heavy metals contamination in Lake Elementaita drainage basin and management effort is required to control contamination to protect the lake ecosystem and biodiversity.

**Keywords:** Lake Elementaita, Heavy Metals Contamination, Water Pollution, Environmental Conservation

## I. INTRODUCTION

Heavy metals are elements whose specific gravity is > than 4.0 g/cm3 and atomic weights varying from 63.5 g/mol to 200.5 g/mol.1 They occur in surface waters in dissolved, colloidal and particulate forms.2 Heavy metals originate from minerals, chemical weathering and also soil leaching.3 The anthropogenic sources include industrial and domestic effluents, landfills, coal, mining of mineral ores and runoff from agricultural farms.4

Heavy metals contamination of water has raised serious concerns due to their effects on human health and aquatic ecosystems.5 Whereas living organisms need minimum amount of some metals such as cobalt, zinc, vanadium and copper in their diets, but the nutrition necessity varies significantly between one species to the other. Excess levels of most metals can lead to health risk to humans since they can antagonize each other or become toxic in the body.6 Non-essential metals, particularly heavy metals of concern are cadmium, chromium, mercury, lead and arsenic since some have no physiological role in the body.7

Lake Elementaita was identified by UNESCO as a Ramsar site in 2005, a wild heritage site in 2011 and bird sanctuary in 1999. This led to the establishment of different human activities in the catchment area.8 Currently the lake resources are threatened by natural and anthropogenic factors which include volcanic activities, overgrazing, discharge from industries and hotels, and agrochemicals from the farms in the upper parts of the catchment.9 The objective of this research was to assess heavy metal contamination in Lake Elementaita drainage basin.

## II. METHODS AND MATERIAL

### A. Study Site Description

Lake Elementaita is a shallow alkaline lake (<1.5 meters deep) with a total surface area of 20 $km^2$. It lies on the Kenyan Great Rift Valley floor at 1776 m altitude above sea level on coordinates of $36^o14'23.92''$E and $0^o26'33.47''$S.[8] It is fed by inflows from two streams. River Mbaruk is the main water source feeding the lake from the Northern part, while River Kariandusi hot springs feeds the lake from the eastern plateaus. However, the lake levels are prone to frequent fluctuations and in some cases its feeders dry up completely.[10] Lake Elementaita basin covers approximately 630 square kms.[8] The lake is reported to have a subsurface flow from Lake Naivasha.[11] The area is characterised by rocky rupture lines, volcanic exposures and craters. The lake environment is preserved by Soysambu and Tutu conservancies.[8]

Lake Elementaita is threatened by siltation as a result of deforestation due to charcoal burning, destruction of vegetation and overgrazing resulting into increased wind and soil erosion.[12] This has led to sedimentation, eutrophication and influx of agrochemicals such as pesticides, nutrients and metals from fertilizers that threaten the lakes' delicate ecosystem.[12] Lake Elementaita catchment is characterised by volcanic soils with a small portions of fertile, deep soil in the higher, eastern area of Gilgil, while the major part of the area is saline, strongly weathered and acidic.[13] The vegetation around Lake Elementaita is made up of Acacia and Euphorbia trees and various bush land (i.e. *Rhus natalensis*) and grassland such as *Cynodon dactylon*.[14] A high amount of former woodland has been cleared or turned into bush and grasslands as a result of farming, grazing and fires. The natural vegetation is at risk of getting even more diminished due to its use as firewood and for charcoal production.[12]

Approximately 30 % of land in the catchment is considered arable and 50 % agro-ecological zones.[12] Farmers in the catchments grow beans and maize and use irrigation for vegetable production.[12] There are a few ranches and large scale farms which produce a large quantities of flowers and crops using irrigation. Livestock husbandry is a also significant in the region particularly for production of milk and meat in areas around Elementaita and Kekopey, supporting the local population economy.[15] Other activities include charcoal production, sand and salt harvesting from the lake for commercial purposes. Overgrazing is a common problem due to a high demand of forage for both livestock by nomadic Maasai and wildlife and often leads to soil erosion after long periods of drought.[12]

The rain pattern in the area is bimodal with long rains experienced from April to June, while short rains occur from October to November.[12]

The Lake is used for breeding the pink backed pelican and lesser flamingoes.[9] Salt harvesting is common on the eastern parts of the lake. Small scale peasant farming is carried out on the western part, while livestock husbandry is mainly practiced in the southern parts of the lake catchment. Table 1 below shows the GPS locations of the sampling sites.

**Table 1.** GPS locations of the sampling sites

| Site | GPS Location | Altitude |
|---|---|---|
| Mbaruk River (MR) | $00^0 28'22''$S and $036^0 15'06''$E | 1,785 m |
| Mbaruk Lake (ML) | $00^o 24'37''$S and $036^o 13'25''$E | 1,787 m |
| Kekopey Spring (KS) | $00^o 28'22''$S and $036^o 15'06''$E | 1,781 m |
| Kekopey Lake (KL) | $00^o 28'22''$S and $036^o 13'06''$E | 1,784 m |
| Lake Elementaita North (EN) | $00^o 24'37''$S and $036^o 13'06''$E | 1,786 m |
| Serena Camp (SC) | $00^o 24'38''$S and $036^o 14'25''$E | 1,782 m |
| Soysambu Ranch (SR) | $00^o 25'23''$S and $036^o 12'31''$E | 1,783 m |

Figure 1 below shows the location and distribution of sampling sites within Lake Elementaita catchment.

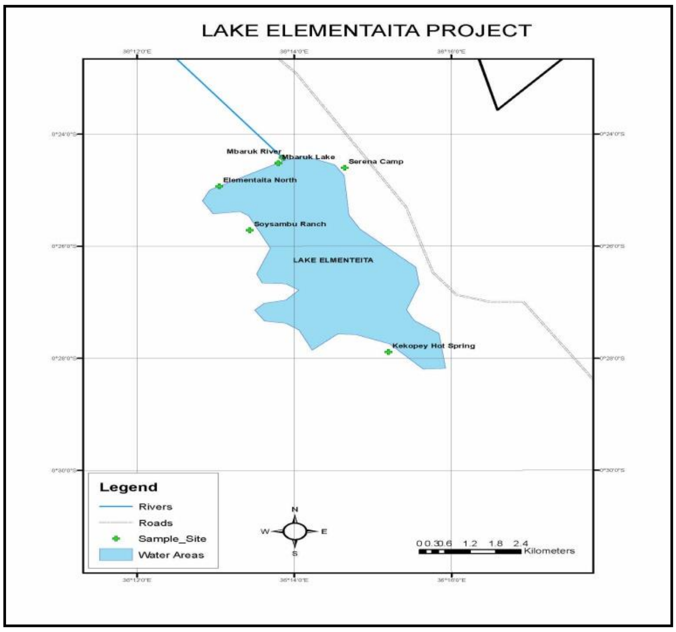


**Figure 1.** Map of the study area showing the distribution of sites

### B. Sampling

Water, soil and sediment samples were collected in the month of October 2014 capturing the dry season. Seven sites were selected based on the activities taking place near the Lake shores. The GPS coordinates were recorded for each site together with the measurement of the physicochemical parameters (pH, Electrical conductivity (EC), Total dissolved Solids (TDS) and Total Suspended Solids (TSS). Water samples were collected by grab method in 1L plastic bottles. Soil and sediment samples were collected by scooping using a clean steel shovel, placed in plastic self-sealing bags. All samples were labelled and placed in Coleman cooler boxes and transported to the laboratory where they were stored in a deep freezer at a temperature of – 20 $^{o}$C prior to analysis.

### C. Chemicals and Reagents

Analytical grade concentrated Hydrochloric (11.9 M), Nitric (14 M), Perchloric acids and distilled water were the main reagents added to the samples before digestion. All the acids were of Analytical Grade from Sigma Aldrich.

### D. Sample Preparation and Chemical Analysis

Sediment and soil samples were thawed and oven-dried at 105 $^{o}$C, ground in a mortar and pestle and sieved through a 2 mm sieve. 1 g samples were taken in triplicates and wet digested at 90$^{o}$C for 60 minutes using 10 ml of analytical grade concentrated hydrochloric (11.9 M) and nitric acids (14 M) in the ratio of 3:1v/v (Aqua regia reagent mixture) to leach out the metals from the matrices. 1 ml of analytical grade perchloric acid was added to the digestion tubes to break down organic matter. After total digestion, samples solutions were filtered through Whatman filter paper No. 1, qualitatively transferred into 50 ml volumetric flasks and topped to the mark using distilled water.

For water samples, 100 ml was digested in triplicates following the aqua regia and perchloric acid method above. Blank samples containing only reagents were subjected to the same digestion procedures for quality control of all samples.

Atomic Absorption Spectrophotometer (AAS) was used for analysis of samples. Calibration curves were prepared for each metal using standard solutions prepared from the metal salts. Appropriate hollow cathode lamps were used for analysis of each element.

### E. Formula for Quantifying Heavy Metals

The following formula was used to quantify heavy metals in soil and sediments:
Concentration in mg/kg = CxV/M
Where C = concentration of metal in the extract (ug/mL); V = volume of extract (mL); and M = weight of sample (g).
For water samples, the formula used was:
[Metal] mg/L in sample = 2Cx$V_1$/$V_2$,
Where C = concentration in mg/L of the metal in the final extract; $V_1$ = volume of the final extract (50 mL); $V_2$ = volume of the original sample (100 mL).

## III. RESULTS AND DISCUSSION

### A. Physicochemical Parameters

pH of water was relatively higher than the WHO recommended range of 6.0-8.5 for most of the samples except the Mbaruk River water Kekopey Spring water which was within the recommended range for drinking water. Similarly, apart from Mbaruk river water, the values for total dissolved solids for the rest of the sites were higher than the USEPA guideline of 500 mg/L.[16] The river water recorded the lowest TDS between 0.07 g/L and 4.21 g/L. All sites recorded high levels of electrical conductivity and TSS, with the highest recorded at Soysambu Ranch (8.40 mS/cm). It ranged between 0.01±0.00 to 0.07 g/L at Mbaruk River and Kekopey Lake, respectively (Table 2).

Table 2: Results of water physico-chemical parameters

| **Site** | **pH** | **TDS (g/L)** | **EC (mS/cm)** | **TSS (g/L)** |
|---|---|---|---|---|
| Mbaruk River | 6.94 | 0.07 | 0.14 | 0.01 |
| L. Elementaita Mbaruk Lake | 10.84 | 4.05 | 8.12 | 0.01 |
| L. Elementaita Kekopey Spring | 8.24 | 2.97 | 5.91 | 0.01 |
| L. Elementaita Kekopey Lake | 10.33 | 3.97 | 7.93 | 0.07 |
| L. Elementaita Serena Camp | 10.36 | 3.85 | 7.68 | 0.05 |
| L. Elementaita Soysambu Ranch | 10.74 | 4.21 | 8.40 | 0.05 |
| Elementaita North | 10.55 | 3.85 | 7.65 | 0.06 |

**B. Heavy Metals Concentrations**

**i. Heavy metal concentrations in water:**

Cadmium concentration in water ranged between 0.04±0.00 mg/L and 0.08±0.01 mg/L which were measured in samples from Kekopey Spring and Serena, Camp respectively. The mean concentration of Cu ranged between 0.08 mg/L and 3.13 mg/L recorded in samples from Mbaruk Lake and Mbaruk River, respectively. On the other hand, the concentration of lead varied from 0.16 mg/L to 0.24 mg/L recorded in samples from Elementaita North and Mbaruk Lake, respectively. Zinc levels ranged between 0.14 mg/L and 0.41 mg/L recorded in samples from Kekopey Lake and Kekopey spring, respectively. Detailed results are shown in Table 3 below.

Table 3. Heavy metals concentration in water (mg/L)

| **Sampling sites** | **Cd** | **Pb** | **Cu** | **Zn** |
|---|---|---|---|---|
| L. Elementaita Mbaruk Lake | 0.06 ±0.03 | 0.24±0.09 | 0.08±0.05 | 0.19±0.01 |
| L. Elementaita Serena Camp | 0.08 ±0.01 | 0.17±0.01 | 0.21±0.28 | 0.26±0.02 |
| L. Elementaita Kekopey Spring | 0.04 ±0 | 0.16±0.01 | 0.08±0.09 | 0.41±0.02 |
| Mbaruk River | 0.05 ±0.01 | 0.17±0.01 | 3.13±0.56 | 0.34±0.03 |
| Elementaita North | 0.06 ±0.01 | 0.16±0 | 0.46±0.02 | 0.33±0.02 |
| L. Elementaita Kekopey Lake | 0.05 ±0.01 | 0.16±0.02 | 0.14±0.01 | 0.14±0.001 |

**ii. Heavy metal concentration in sediments:**

Table 4 shows the concentrations of heavy metals in sediments. Zinc concentrations ranged between 45.73 mg/kg and 106.28 mg/kg. The lowest concentration was measured in samples from Serena Camp while the highest was recorded in samples from Kekopey Spring sediments. Cadmium concentration in sediments varied from 2.06 mg/kg to 2.89 mg/kg, while copper varied from 2.93±0.66 mg/kg to 134.97 mg/kg. Lead recorded the lowest frequency with concentrations ranging from bdl to 3.14 mg/kg.

**Table 4.** Heavy metals concentrations in sediments (mg/kg)

| **Sampling sites** | **Cd** | **Pb** | **Cu** | **Zn** |
|---|---|---|---|---|
| L.Elementaita Kekopey Spring | 2.36± 0.50 | 3.14± 0.49 | 12.4±3.56 | 106.28 ±2.89 |
| L.Elementaita Mbaruk Lake | 2.24± 0.17 | bdl | 7.43±0.54 | 93.08± 8.09 |
| L.Elementaita Soysambu Ranch | 2.07± 0.08 | bdl | 2.93±0.66 | 63.13± 0.42 |
| Mbaruk River | 2.72± | 2.29± | 5.92±2 | 100.56 |

| | | | | |
|---|---|---|---|---|
| | 0.17 | 0.23 | .51 | ±0.94 |
| Kekopey Lake | 2.89± 0.42 | bdl | 34.70± 10.29 | 61.91± 7.02 |
| Elementaita North | 2.06± 0.42 | bdl | 134.07 ±27.05 | 91.35± 2.12 |
| L.Elementaita Serena Camp | 2.89± 0.59 | bdl | 12.74± 0.17 | 45.73± 9.44 |

**iii. Heavy metals in soil samples:**

Zinc registered the highest concentration in all the soil samples with levels ranging from 57.95 mg/kg to 86.95 mg/kg. Kekopey Lake and Lake Elementaita North soils recorded the lowest and the highest concentrations of zinc, respectively. Cadmium concentration ranged between 2.78 mg/kg and 6.86 mg/kg recorded in samples from Kekopey Lake soil and Elementaita North Soil, respectively. The concentration of copper in soil samples ranged between 2.96 mg/kg and 35.79 mg/kg in samples from Mbaruk River soil and Lake Elementaita Serena Camp, respectively. Lead concentration in soil ranged between 10.37±0.08 mg/kg and 17.97 mg/kg detected in samples from Lake Elementaita Kekopey Hot Spring soil and Mbaruk River soil, respectively (Table 4).

**Table 4.** Heavy metals concentration in soil (mg/kg)

| Sampling sites | Cd | Pb | Cu | Zn |
|---|---|---|---|---|
| L.Elementaita Soysambu Ranch | 3.01± 0.25 | 10.49 ±0.19 | 4.31± 1.88 | 70.76 ±1.04 |
| L.Elementaita Serena Camp | 3.25± 0.42 | 12.36 ±0.99 | 35.79 ±8.87 | 68.71 ±0.72 |
| L.Elementaita Kekopey Lake | 2.78± 0.08 | 10.38 ±0.99 | 7.73± 2.11 | 57.95 ±6.68 |
| L.Elementaita Kekopey Spring | 3.43± 0.17 | 10.59 ±0.19 | 9.21± 2.08 | 76.66 ±16.03 |
| Elementaita North | 6.86± 0.17 | 11.04 ±0.88 | 4.03± 0.54 | 86.95 ±5.55 |
| L.Elementaita Mbaruk Lake Soil | 5.56± 0.00 | 15.77 ±0.69 | 34.26 ±1.73 | 74.84 ±3.16 |
| Mbaruk River | 6.09± 0.25 | 17.97 ±0.47 | 2.96± 0.39 | 75.86 ±6.81 |

## C. Discussion

***i. Physico-chemical parameters:***

pH of Lake Elementaita samples was relatively high due to the fact that the lake originates from carbonaceous volcanic rocks.[17] The lower pH at both mouths of the Kekopey Spring and Mbaruk River could be attributed to the high inflow of fresh water from the hot spring and Mbaruk River.

The high TDS values in all sites could be associated with high concentration of dissolved minerals as a result of volcanic activities and high evaporation rates experienced in the lake.[18] High TSS values especially at Serena camp could be attributed to the effect of surface runoff from agricultural activities and discharge from commercial establishments around the lake such as hotels.

***ii. Heavy metals in soil:***

The high cadmium mean level in soil may have been contributed by cadmium-containing fertilizers and sewage sludge.[19] Since cadmium is used in paints and plastics manufacturing industries, there is also possibility of some of it entering the Lake in the form of industrial or municipal effluent. The high levels of copper in soil around Mbaruk River might could be attributed to the discharge from the nearby industries using copper as one of the ingredients in the processes. The mean copper concentrations in the study area were above the WHO standard guideline values of 25 mg/kg for the survival of aquatic organisms[20,21] indicating a potential risk to the lake ecosystem.

The high concentrations of lead in soil could be associated to nearby busy highway since in the past high amounts of leaded fuels were used. In addition, spillage of leaded gasoline could also give rise high levels of lead. Other important sources could be atmospheric deposition, industries dealing with paints and batteries, and municipal discharges could as well. Most of the sites in the study area recorded lead concentration higher than the recommended value of lead in soil which is 35 mg/kg.[20]

The results of zinc concentrations in all the sampling sites did not exceed the WHO recommended limit of 123 mg/kg.[20] Sources of copper in the sediment can originate from the overlying water and leaching from the soil as a result of runoff and wet and dry deposition. The high concentration of copper in Mbaruk River might could be attributed to agricultural activities from the upper side of the area especially the use of fertilizers, fungicides and insecticides. The mean copper concentrations in the study area were above the WHO standard values of 25 mg/kg for the survival of aquatic organisms.[20]

***iii. Heavy metals in sediments:***

The high lead concentration in the lake sediment indicates an anthropogenic source. The lake is situated along the busy Nairobi-Nakuru highway; the vehicle sources could therefore be the major contributor of lead in this lake. Other sources may possibly include industrial wastes and from water pipes, lead acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors and plastic stabilizers.[20,22] The source of zinc concentrations in sediments could be from zinc Carbonates used as pesticides.[23] The results on zinc concentrations in all the sampling sites did not exceed the WHO recommended limit of 123 mg/kg.[21]

***iv. Heavy metals in water:***

The presence of cadmium in water could have been attributed by high mobility of Cd due to weak binding to soil and sediments,[24] which could also result into most of it being leached out. From the results obtained, cadmium in water samples was found to be below WHO and CWQGs recommended value of 0.005 mg/L for the protection of aquatic life.[25]

The high concentrations of copper in samples from Elementaita North could be attributed to agricultural activities and the presence of a local industry which treats electrical poles using various preservatives that include fungicides and insecticides as well as the use of fertilizers.[26,27] The mean levels of copper in the study area were above CWQG of 1 mg/L for the protection of aquatic life.[25] The concentrations of lead in water recorded were above WHO and CWQGs recommended value of 0.01 mg/L for protection of aquatic life. The concentrations of zinc in water samples were below the WHO and CWQGs recommended value of 5 mg/L for the protection of aquatic life.[25]

## IV. CONCLUSION

Significant amount of heavy metals such as cadmium, copper, zinc, chromium and lead were measured in water, sediment and soil samples from Lake Elementaita drainage basin. Matrices with the highest levels were soils and sediments. Copper and lead concentrations were found to be above the WHO recommended limit for drinking water, while zinc and cadmium were below the limit. High concentration of lead could be attributed to old releases when lead fuel was heavily utilized. In addition, spillages of leaded gasoline from cars especially during intense traffic along a busy Nairobi-Nakuru highway could be a potential influencing factor. Copper contamination could be attributed to agrochemical inputs and industrial activities using copper, chromium and arsenate as ingredients for wood preservation.

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