# DISTRIBUTION OF HEAVY METALS IN VARIOUS LAKE MATRICES; WATER, SOIL, FISH AND SEDIMENTS: A CASE STUDY OF THE LAKE NAIVASHA BASIN, KENYA

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**Abstract**

Water, sediments, soil and fish, common carp *(Cuprinus carpio),* largemouth blackbass *(Micropterus salmoides),* tilapia *(Oreochromis leucostictus)* and mirror carp *(Cyprinus spectacularlus)* from the Lake Naivasha basin were analysed for lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu) and nickel (Ni). Samples were collected from the Main Lake, Lake Oloidien, Crescent Lake, River Malewa, Naivasha Municipal Council Sewer entry point, flower farm discharge canals and the Kenya Wildlife Services (KWS) Sanctuary (Joan Roots Farm). Fish samples were bought from fishermen while still alive and identified by the Kenya Marine and Fisheries Research Institute (KEMFRI) staff. The heavy metal concentrations were determined using flame atomic absorption spectrophotometry (AAS). The mean sediment concentrations (in μg/g dry weight) were 62.5 ± 26.5 for Ni, 42.39 ± 17.95 for Zn, 32.71 ± 16.94 for Pb, 1.52 ± 0.87 for Cu and 1.65 ± 0.96 for Cd respectively, whereas those in soil (in μg/g dry weight) were 25.69 ± 10.62 for Pb, 2.56 ± 1.40 for Cd, 53.28 ± 19.41 for Zn, 52.05 ± 22.64 for Ni and 1.02 ± 0.57 for Cu respectively. The mean heavy metal contents in fish (in μg/g wet weight) were 1.7 ± 0.91 for Pb, 0.33 ± 0.30 for Cd, 8.03 ± 2.7 for Zn, 14.34 ± 4.4 for Ni and 0.3 ± 0.11 for Cu, whereas those in the water column (total content) were 16.56 ± 9.55 μg/L for Pb, 12.69 ± 9.54 μg/L for Cd, 1.34 ± 0.48 mg/l for Zn, 0.18 ± 0.13 mg/l for Ni and 5.68 ± 3.71 μg/L for Cu respectively. The study shows that the most important sources of heavy metals pollution in the Lake Naivasha basin are River Malewa, geochemical processes, flower farms and the Naivasha Municipal Council.

**Key words:** Lake Naivasha, pollution, heavy metals, sediments, soil, fish, Oloidien

## 1.0 Introduction

### 1.1 Location of Lake Naivasha

Lake Naivasha lies between 0° 08' to 0° 55' S and 36° 00' to 36° 45' E altitude (Plate 1)

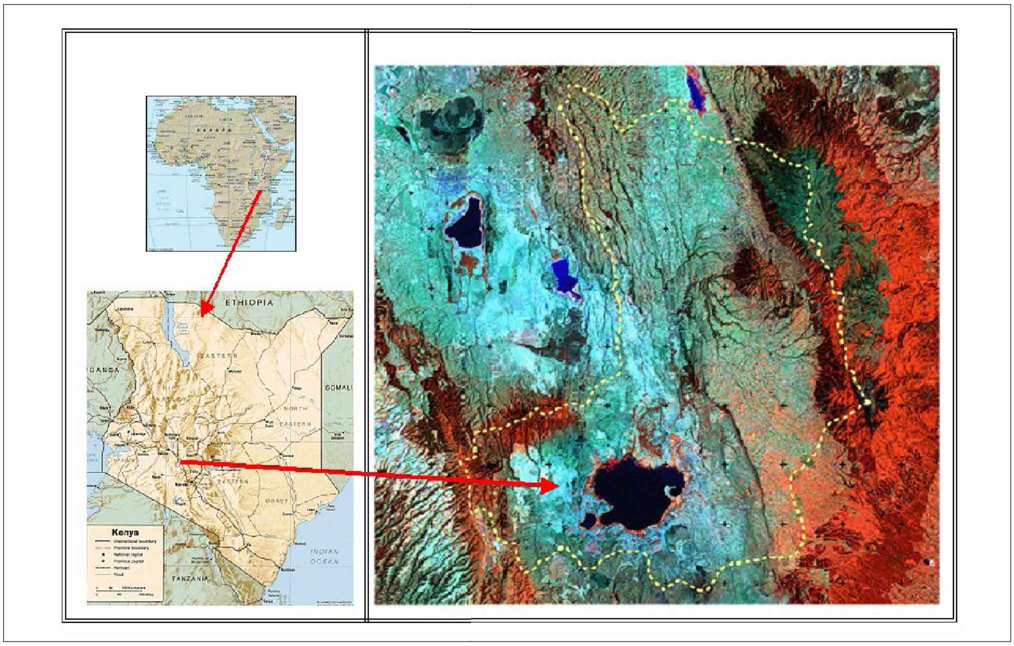


*Plate 1: Location of the Lake Naivasha drainage basin*

1,890 m asl, on the floor of Africa's Eastern Rift Valley, covering approximately 140 km$^2$ (Harper, 1993; Becht *et al.,* 2005). It is the largest fresh water lake in Kenya (Hartley, 1985). The overall climate of the Eastern Rift Valley is semi-arid (Becht *et al.,* 2005). The lake provides one of the most important wetlands in the floor of the Rift Valley. Lake Naivasha is composed of three lakes; the Main Lake, Lake Oloidien and Crescent Lake. The lake forms a home to many species of birds, buffaloes, wildbeeste, fish eagles, etc. (Hartley, 1985: Becht and Harper, 2002; Birdlife, 2007).

### 1.2 The Lake Naivasha Wetland

The wetlands lie in a high altitude trough of the Gregory Rift Valley with the Nyandarua ranges to the east forming a ring up to 4,000 m and Mau escarpment to the west (up to 3,100 m), the catchment area is approximately 3,000 km$^2$ (Harper, 1993; LNROA, 1993; Becht *et al.,* 2005). The wetland soils are mainly sediments of a former larger lake and are influenced by the volcanic origins of the basin rocks and soils (Gray 2000; Gitahi *et al.,* 2002). The wetlands receive surface drainage from two perennial and several ephemeral streams, the largest being the Malewa River which, together with the next largest, the Gilgil River form a floodplain and a delta where it enters the lake from the north. The mean depth of the main lake is around 4 m with the deepest part of the submerged crater being 16 m (Becht *et al.,* 2005).

### 1.3 Environmental Issues Facing the Lake Naivasha Basin

The Lake Naivasha ecosystem has undergone significant ecological changes as a result of human settlements, power generation, and reclamation of the papyrus belt, flower farming and other human activities (Gitahi, 2005; Njogu *et al.,* 2010). The marked ecological changes have led the lake to be classified as a Ramsar wetland in 1995 (Database, 1995). The lake was listed in the Montreux listing in 2008 as a significant site requiring urgent action to save it from extinction (EAWS, 2009: RCW, 2010). The lake has experienced frequent episodes of chemical pollution in the recent past that have led to the death of millions of fish (Food and Waterwatch, 2008; Gitonga, 2010). The flower industry and other agricultural sectors are agrochemical intensive industries, the use of agrochemicals in the catchment have led to their introduction into the watercourse directly, as drift during application, deposition and as run off during the rainy season (Tarras *et al.,* 2002; Campbell *et al.,* 2003; Njogu *et al.,* 2010). The flower sector is one of the fastest growing sectors in Kenya today with most of the farmland around the lake practising intensive irrigated agriculture (plate 2). The land covered by irrigation crops has also increased tremendously in recent years.

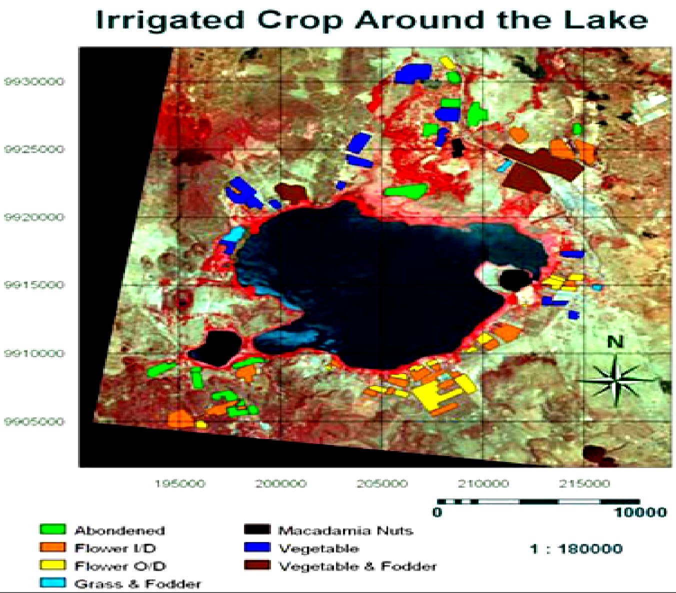


*Plate 2: Area under irrigated crop in the basin Lake Naivasha drainage basin*

Some heavy metals are active ingredients in agrochemicals, others are present as contaminants (Tyagi and Mehra, 1990; Ochieng' *et al.,* 2007; Food and Waterwatch, 2008). The use of agrochemicals containing heavy metal has led to their introduction to the lake. There is controversy over the sources of heavy metal pollution in the lake, with flower farmers claiming that most of the pollution originates from the small-scale farmers upstream (Njuguna, 2005; Ojanji, 2007). This study was carried out during the months of November and December 2008 to determine the sources, concentrations and distribution of lead, copper, cadmium, nickel and zinc in soil, fish, water and sediments in the Lake Naivasha basin.

## 2.0 Materials and Methods

The study was conducted at the Jomo Kenyatta University of Agriculture and Technology's Chemistry Research Laboratory.

## 2.1 Laboratory Procedures and Quality Control

Sample preparations and analysis were carried out using standard methods of analysis (Herlich, 1990; APHA, 1995).

## 2.2 Sampling and Sample Sites

Soil, water, and sediment samples were collected at random from the Lake Naivasha basin. Samples were collected in triplicates from 12 sampling sites along River Malewa, Main Lake, Lake Oloidien, Crescent Lake, flower farm discharge canals, and the KWS sanctuary (Plate 3)

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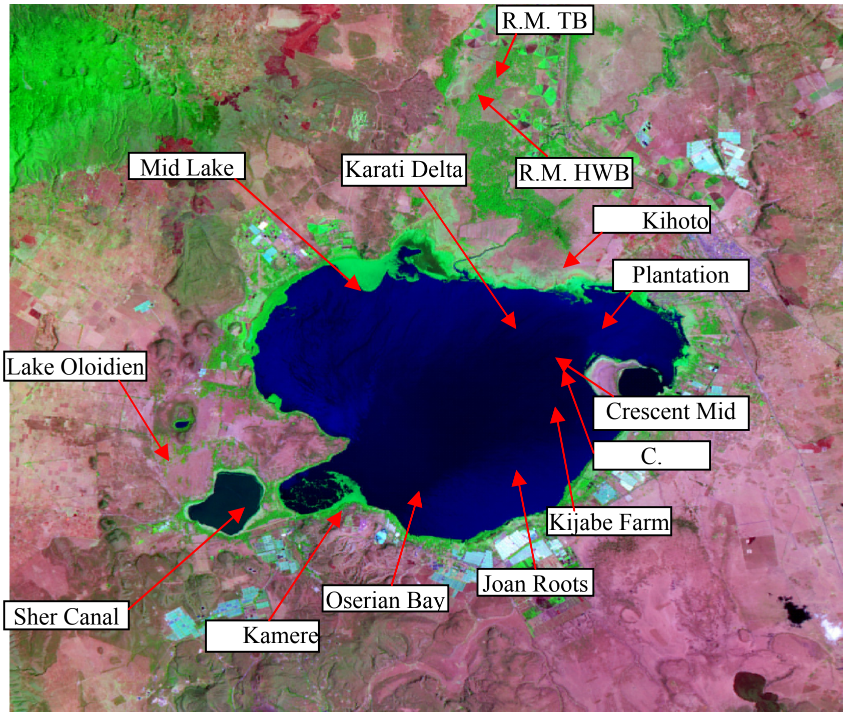


*Plate 3: Sampling sites at the Lake Naivasha drainage basin*

Four fish species *O. leucostictus, C. carpio, M. salmoides* and *C. spectaculurus* were bought from fishermen at the Kamere Public Beach and identifications done by the KEMFRI staff. Six samples of each fish species were analysed to give a total of 24 samples. A total of 12 sampling sites were used in the study, as illustrated in Plate 3. The siteswere chosen considering relevance as point sources of pollution, middle of lake, shoreline, along feeder rivers discharge canals and undisturbed sites to serve as control. Samples we collected during the months of November and December 2008.

### 2.3 Sample Pre-treatment
Water samples were collected as grab samples in pre-cleaned plastic bottles in triplicates from and treated with nitric acid (2 mL/L), these were stored in a cool box and transported to the laboratory. Fish samples were wrapped in polythene bags and stored in cool boxes then were transported to the laboratory under ice. Soil samples were collected in triplicates, approximately 500 g samples were scooped using a shovel at a maximum depth of 15 cm and mixed evenly before a sample was taken. These were stored in polythene bags. Sediment samples were sampled as grab samples using the Ekman dredge sampler in triplicates and wrapped in polythene bags.

### 2.4 Soil and Surface Sediments
Samples were dried in the oven overnight at 105 $^{\circ}$C, then crushed in a mortar and pestle and sieved to remove plant parts and debris. One gram portions were weighed using digital analytical balance with an accuracy of 0.001 grams and acid digested using a mixture of nitric acid and perchloric acid (1:3) until clear solutions were realised. The resulting solutions were filtered using 0.45 µm filter papers and topped to 50 ml in 50 ml volumetric flasks with distilled de-ionised water. The digests were stored in the refrigerator in pre-cleaned plastic bottles and analysis carried out within one week.

### 2.5 Fish Samples
Two portions of fish muscle were cut and homogenised in a pestle and mortar. Two grams wet weight, portions were taken in triplicates for each sample and acid digested using a mixture of nitric acid and perchloric acid (1:3). These were wet oxidised as described above.

### 2.6 Water Samples
Water samples were thoroughly mixed and aliquots of 50 ml taken in triplicates. These were acid digested with a mixture of nitric acid and perchloric acid (l:3) until clear solutions were obtained, digests were filtered and stored in plastic bottles.

### 2.7 Limnology Data
Limnology data was determined to assess the quality of water in the lake. Temperature and dissolved oxygen were measured using ion selective electrodes. Secchi depth measurements were done using a Secchi disk attached to a graduated string, measurements were done in triplicates.

### 2.7 AAS Analysis
Flame atomic absorption spectrophotometer (AAS - Buck Scientific VGP 210 Model) was used in the analysis. The concentrations of the metals were determined in triplicates. The accuracy and precision of the analytical procedure were determined. A series of standards were prepared for instrumental calibration by serial dilution of working solutions (100 ppm) prepared from analytical grade stock solutions (1000 ppm) from BDH Poole, USA. A standard and blank sample was run after every seven samples to check for instrumental drift.

## 2.8 Data Analysis

The concentrations of heavy metals in various matrices are presented as arithmetic mean with standard deviation (mean ± standard deviation). The results are presented in tables and bar graphs. Statistical analyses were done at p = 0.05 (Miller and Miller, 1998).

## 3.0 Results and Discussions

### 3.1 Physicochemical parameters

The limnology data for the sampling sites are presented in Table 1.

*Table 1: Limnology data*

| Sites | Temperature ($^0$C) | Dissolved Oxygen (mg/l) | Secchi Depth (cm) |
|---|---|---|---|
| Oserian Bay | 24 ± 2.5 | 7.9 ± 1.1 | 55 ± 1.5 |
| Mid Lake | 24 ± 1.5 | 8.45 ± 1.1 | 65 ± 2.0 |
| Karati Delta | 23 ± 1.0 | 7.9 ± 1.1 | 30 ± 1.5 |
| C. Shoreline | 26 ± 1.2 | 6.9 ± 1.2 | 45 ± 2.5 |
| C. Mid | 22 ± 1.3 | 7.90 ± 1.0 | 110 ± 2.5 |
| Kihoto Sewer | 25 ± 1.2 | 8.5 ± 1.1 | 53 ± 1.1 |
| Lake Oloidien | 23 ±1.5 | >20 | 10 ± 1.5 |
| Sher Canal | ND | ND | ND |
| R.M. TB | 22.3 ± 1.0 | 7.9 ± 1.0 | 45 ± 2.5 |
| R.M. HWB | 24.2 ± 1.0 | ND | 35 ± 2.0 |

*(Mean ± standard deviation, n = 3, ND – Not Determined)*

The Secchi depth (SD) ranged within 10 to 110 centimeters in the basin. The SD, temperature and dissolved oxygen (DO) levels of the present study are higher than those reported earlier (Campbell *et al.,* 2003). Increased SD and DO indicate improved water quality, increase in temperature could be due to current trends in global warming. The highest SD was observed at crescent mid and the lowest at the Karati delta indicating inflow of suspended matter. The low SD at Lake Oloidien was due to the presence of a large population of blue green algae.

## 3.2 Heavy Metal Concentrations in Sediments

The heavy metal contents in sediments are presented in Table 2 and Figure 1, indicating wide variations of heavy metals in the Lake Naivasha basin.

*Table 2: Heavy Metals Concentrations in Sediments (µg/g)*
*Mean ± Standard deviation, n = 3. Key: R.M. - River Malewa, TB – Turasha Bridge, C – Crescent*

| | Copper | Lead | Zinc | Cadmium | Nickel |
|---|---|---|---|---|---|
| Oserian Bay | 1.49 ± 0.31 | 28.03 ± 2.1 | 48.01 ± 2.1 | 1.68 ± 0.51 | 55.71 ± 1.51 |
| Mid Lake | 1.84 ± 0.29 | 26.14 ± 1.5 | 34.86 ± 3.2 | 1.63 ± 0.51 | 46.71 ± 2.1 |
| Karati Delta | 2.46 ± 0.01 | 43.94 ± 0.65 | 63.62 ± 3.6 | 0.74 ± 0.05 | 100.31 ± |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | 3.72 |
| C. Shoreline | 3.22 ± 0.31 | 43.18 ± 0.99 | 70.22 ± 3.2 | 2.53 ± 0.52 | 118.42 ± 5.2 |
| Crescent Mid | 1.13 ± 0.07 | 31.82 ± 1.5 | 37.97 ± 2.5 | 2.47 ± 0.58 | 38.81 ± 2.79 |
| Kihoto Sewer | 2.21 ± 0.05 | 57.38 ± 3.5 | 62.38 ± 2.5 | 3.26 ± 0.65 | 57.89 ± 2.2 |
| Lake Oloidien | 2.21 ± 0.05 | 42.73 ± 0.96 | 62.38 ± 2.5 | 2.55 ± 0.68 | 66.71 ± 2.1 |
| Sher Canal | 2.66 ± 0.51 | 26.13 ± 0.99 | 65.28 ± 1.5 | 3.66 ± 0.45 | 73.68 ± 2.3 |
| R.M. HWB | 1.84 ± 0.54 | 60.23 ± 2.21 | 62.38 ± 2.5 | 3.35 ± 0.36 | 101.31 ± 3.8 |
| R.M. TB | 2.31 ± 0.25 | 38.18 ± 0.99 | 45.56 ± 3.2 | 2.87 ± 0.69 | 68.42 ± 3.2 |

Nickel is the most predominant metal followed by zinc, lead, copper and cadmium in that order. The study shows wide variability in heavy metal contents between sites. Sites along River Malewa, discharge canals and Kihoto sewer point show the highest concentrations of lead, zinc and nickel compared to other sites. The Karati Delta where most water enters the lake also shows high nickel content indicating inflows from River Malewa. There is also high concentration at the River Malewa highway bridge (downstream) and the Sher discharge canal. The high metal content at the River Malewa highway bridge could be as a result of discharge from the Delamere estates, the largest farms upstream and traffic pollution from the Nairobi-Nakuru highway.

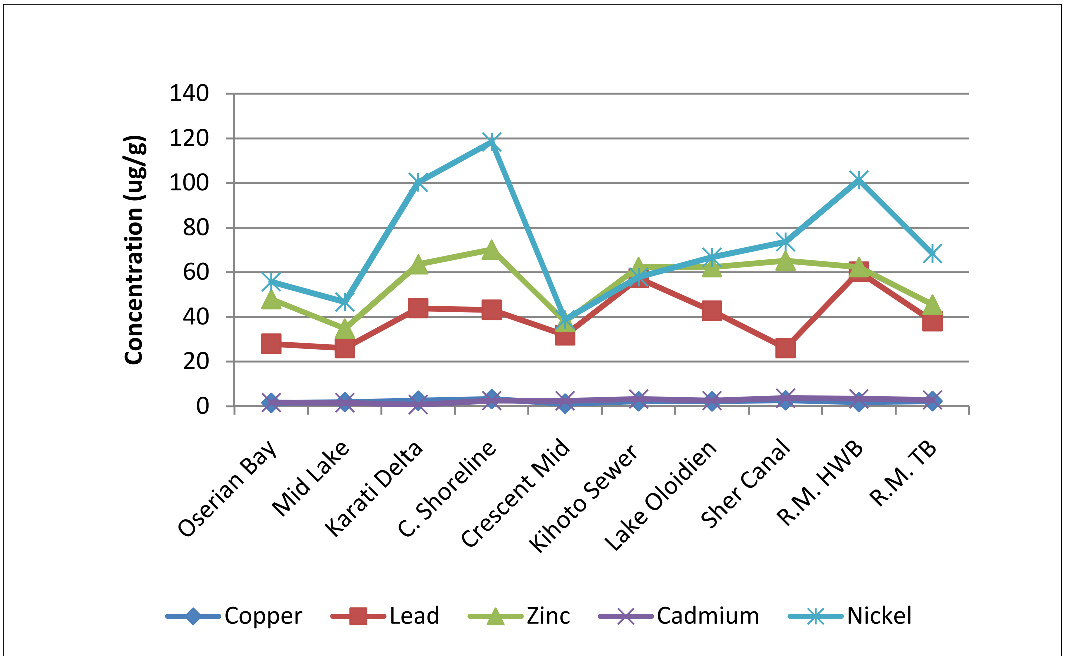


*Figure 1: Spatial variations of heavy metals within sampling sites*

The data indicates that the copper concentrations are low. This could be due to low copper concentrations in inflows. There could also be some chemical processes that lead to the release of copper from the sediments. The highest lead is found at the River Malewa highway bridge followed by Kihoto Sewer entry point and the Karati Delta. The mid crescent lake has the lowest amount of metals in sediments which could be due lack of discharge canals and other inflows into the lake. Kihoto sewer point shows high levels of lead, zinc and nickel indicating inflow from Naivasha municipal sewer treatment plant. Lake Oloidien shows relatively high concentrations. This could be due to bio-concentration by blue-green algae which settle to the floor of the lake. Being a soda lake, the metal contents are also expected to be high.

Statistical analysis of inter-metallic relationship using Pearson's correlation coefficient at $p = 0.05$ reveal positive correlation and significant regression relation among the metals. The correlation coefficients with $p < 0.05$ were: Pb – Cu ($r = 0.1$), Pb – Zn ($r = 0.49$), Cu – Zn ($r = 0.73$), Cu - Cd ($r = 0.16$), Cu - Ni ($r = 0.68$), Pb - Cd ($r = 0.16$), Pb - Ni ($r = 0.52$), Zn - Cd ($r = 0.29$), Zn - Ni ($r = 0.69$) and Cd - Ni ($r = 0.69$) in sediments. The highest positive correlation was found between Cu - Zn ($r = 0.73$) and the lowest was between Pb - Cu ($r = 0.1$). The positive correlations between heavy metal concentrations suggested either a common or a similar geochemical behaviour origin. The low positive correlations between lead and copper could mean that they are coming from different sources or have different chemical behaviour in the lake bed.

Results of this study agree with levels reported earlier by Ochieng' *et al.,* 2002, Tarras *et al.* (2002) and Moturi *et al.* (2005). The study however reveals an increase in cadmium contamination in the lake bed and increased inflow of suspended solids in inflows.

### 3.3 Heavy Metal Contents in Water

The heavy metal content in water data is presented in Table 3 and Figure 2.

*Table 3: Heavy metals concentrations in water samples from Lake Naivasha basin*

| | **Cu (µg/L)** | **Pb (µg/L)** | **Cd (µg/L)** | **Zn (mg/l)** | **Ni (mg/l)** |
|---|---|---|---|---|---|
| Oserian Bay | 2.42 ± 0.51 | 26.62 ± 1.1 | 12.58 ± 0.65 | 1.03 ± 0.04 | 0.08 ± 0.01 |
| Mid Lake | 1.06 ± 0.05 | 9.15 ± 1.6 | 4.65 ± 1.21 | 0.97 ± 0.7 | 0.13 ± 0.07 |
| Karati Delta | 1.88 ± 0.05 | 11.25 ± 1.7 | 16.77 ± 2.44 | 0.80 ± 0.09 | 0.17 ± 0.01 |
| C. Shoreline | 4.29 ± 0.56 | 5.61 ± 2.1 | 11.18 ± 1.12 | 1.33 ± 0.05 | 0.13 ± 0.05 |
| C. Mid | 5.23 ± 0.67 | 23.02 ± 1.2 | 3.73 ± 0.94 | 1.34 ± 0.57 | 0.18 ± 0.05 |
| Kihoto Sewer | 4.69 ± 0.62 | 10.1 ± 1.2 | 6.52 ± 0.32 | 1.02 ± 0.08 | 0.21 ± 0.11 |
| Lake Oloidien | 4.69 ± 0.12 | 11.04 ± 2.1 | 38.21 ± 2.3 | 1.41 ± 0.45 | 0.45 ± 0.07 |
| Sher Canal | 13.56 ± 0.99 | 36.41 ± 5.1 | 2.79 ± 0.25 | 1.90 ± 0.01 | 0.24 ± 0.11 |
| R.M. TB | 4.03 ± 0.13 | 18.23 ± 3.1 | 11.77 ± 2.44 | 1.53 ± 0.65 | 0.13 ± 0.07 |
| R.M. HWB | 11.01 ± 0.87 | 14.31 ± 1.5 | 14.92 ± 1.1 | 1.38 ± 0.35 | 0.13 ± 0.06 |

*Mean ± standard deviation, n = 3 Key: R.M. - River Malewa, TB – Turasha bridge, C – Crescent*

The results indicate that zinc is the most predominant metal followed by nickel, lead, cadmium and copper respectively. Analysis using Pearson's correlation coefficient ($p < 0.05$) revealed negative relationship between SD and metals. The Pearson's correlation coefficient for lead and SD is -0.26, Cu ($r = -0.27$), Zn ($r = -0.41$), Ni ($r = -0.50$), and Cd ($r = -0.70$). Negative correlations between heavy metal concentrations and SD show an inverse relationship, this suggests that most of the metals are adsorbed on suspended particulate matter.

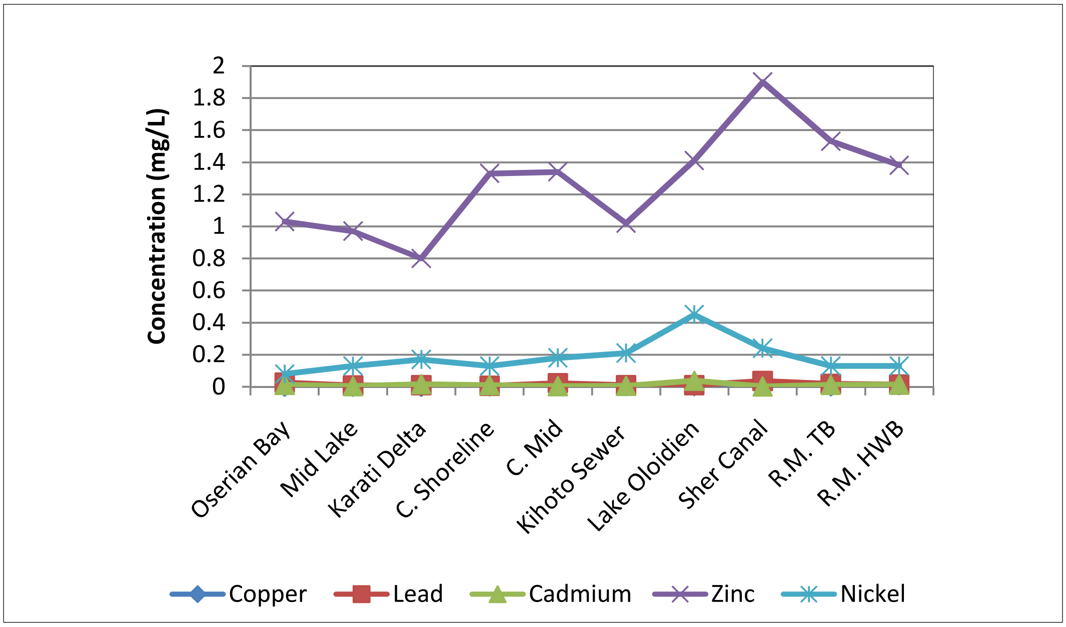


*Figure 2: Spatial variations of metals water concentrations within sampling sites*

The highest copper content is found at the Sher discharge canal, indicating inflows from the flower farms. The second largest concentration is found at the River Malewa highway bridge along the Nairobi -Nakuru highway. This could be as a result of traffic pollution or discharge from the Delamere Estates upstream. Oserian bay despite having several canals shows low copper content in the water; this could be due to the uptake of the labile copper by the thriving water hyacinth and other aquatic plants growing in this region. The Kihoto sewer point also has high metal content compared to other sites. This could mean there in inflow of metals from the sewer point. The Karati Delta shows low copper content compared to the amounts recorded at the river Malewa highway bridge. This could be as a result of dilution by the water from River Gilgil or removal of copper through adsorption onto particulate matter as the river flows downstream.

Pearson's correlation coefficient ($p < 0.05$) revealed a degree of correlation and significant regression relation among the metals. This indicates identical behaviour of metals in the water column and could indicate origin from similar sources. The correlation coefficients with $p < 0.05$ were; Cu - Pb ($r = 0.51$), Cu - Zn ($r = 0.78$), Cu - Ni ($r = 0.18$), Pb - Zn ($r = 0.58$)

and Cd - Ni (r = 0.67). There was however inverse relationships between Pb - Cd (r = -0.25), Cu - Cd (r = -0.15), Ni - Pb (r = -0.06), Cd - Zn (r = -0.04) and Ni - Zn (r = -0.29) This could be due to origin from different sources or antagonism.

The Pearson's product mean for water and sediments indicate an interesting pattern at $p < 0.05$, the correlation coefficients were positive for Cu (r = 0.12), Zn (r = 0.11), and negative for Pb (r = -0.31), Cd (r = -0.03) and Ni (r = -0.33). The positive correlation could signal exchange between sediments and the water column maintaining a state of equilibrium whereas the inverse relationship indicates removal of metals from either sediments to the water column and vice versa.

Heavy metal concentrations in the water column agree with those reported by Simiyu and Tole (2000) and Kubo (2004) and are lower than those reported by Kisamo (2003) and Kamau *et al.* (2007, 2008) for copper. The concentrations fall within the range found of fresh water ecosystems (Alloways and Arynes, 1993) and are below the maximum acceptable levels in drinking water (WHO, 1984; CCNE, 1991; Manahan, 1991; Murley, 1992).

### 3.4 Heavy Metal Concentrations in the Soil

The heavy metal concentrations in the soil from the basin are presented in Table 4 and Figure 3.

*Table 4: Heavy metal concentrations in soil (µg/g)*

| | **Copper** | **Lead** | **Zinc** | **Cadmium** | **Nickel** |
|---|---|---|---|---|---|
| P. Plant | 1.04 ± 0.06 | 17.61 ± 1.0 | 37.43 ± 1.61 | 3.51 ± 0.5 | 46.49 ± 2.3 |
| Kamere Beach | 0.60 ± 0.05 | 27.27 ± 0.9 | 64.19 ± 2.2 | 1.12 ± 0.1 | 59.21 ± 1.5 |
| Kijabe Farm | 0.79 ± 0.12 | 17.04 ± 2.1 | 44.26 ± 2.1 | 2.24 ± 0.3 | 53.94 ± 2.1 |
| R.M. HWB | 0.66 ± 0.11 | 48.86 ± 1.2 | 81.33 ± 3.2 | ND | 69.73 ± 1.3 |
| Joan Roots | 0.80 ± 0.19 | 28.41 ± 1.1 | 46.96 ± 2.2 | 1.44 ± 0.2 | 55.26 ± 2.5 |
| R.M. TB | 2.14 ± 0.50 | 17.04 ± 1.0 | 77.25 ± 2.5 | 3.07 ± 0.1 | 84.21 ± 2.8 |
| Lake Oloidien | 1.05 ± 0.06 | 31.81 ± 1.3 | 64.19 ± 2.2 | 1.45 ± 0.1 | 78.94 ± 2.5 |

*Mean ± Standard Deviation, n = 3, ND – Not determined, Key: P - Plantations,R.M. – River Malewa, TB – Turasha bridge*

The soil is rich in nickel followed by zinc, lead, cadmium and copper respectively. The highest zinc concentration is found in soil samples from the River Malewa Highway Bridge and highest nickel content in the River Malewa Turasha Bridge. Lake Oloidien shows high zinc, nickel and lead content compared to other sources. The Joan Roots site indicates that nickel is the most predominant metal followed by zinc, lead, cadmium and copper respectively. This supports the theory that most of the nickel in the sediments is washed down into the lake during the rainy period. The study shows that there are higher metal contents in the upper catchment compared to lower.

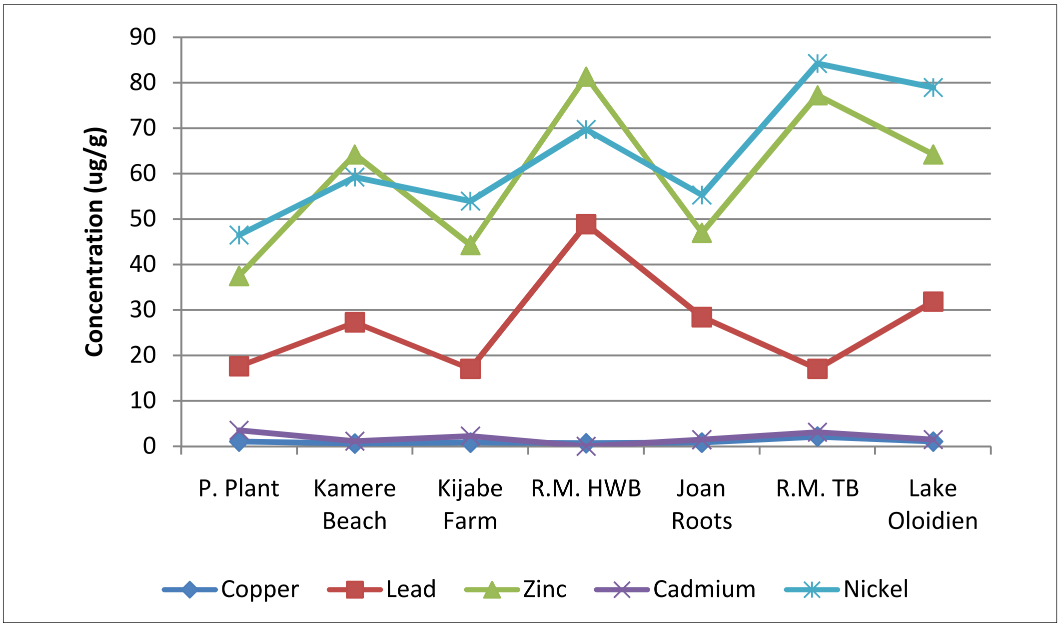


*Figure 3: Spatial variations of heavy metal concentrations in soil*

### 3.5 Heavy Metal Concentrations in Fish

The weight, length, lipid content and moisture content of specimens were determined and are presented in Table 5.

*Table 5: Lipid content, length, moisture, and weight of fish from Lake Naivasha*

| **Parameters** | ***O. leucostictus*** | ***C. carpio*** | ***C. spectacularlus*** |
|---|---|---|---|
| Lipid content (%) | 1.87 ± 1.0 | 0.78 ± 0.1 | 0.92 ± 0.2 |
| Moisture content (%) | 81.89 ± 3.1 | 79.22 ± 3.8 | 79.78 ± 1.3 |
| Weight (g) | 202.69 ± 33.1 | 829.96 ± 196.7 | 765.13 ± 29.8 |
| Length (cm) | 22.57 ± 1.2 | 41.1 ± 4.0 | 41.66 ± 0.8 |

*Mean ± Standard Deviation, n = 6*

The highest lipid content was reported in *O. leucostictus* followed by *C. spectacurlus and C. carpio.* The moisture content was not significantly different between species. The weight and length of specimens varied widely, *O. leucostictus* showed the lowest weight and length. The heavy metal concentrations are presented in Table 6 and Figure 4.

*Table 6: Heavy metal concentrations (µg/g, wet weight) in fish from Lake Naivasha*

| | **O. leucostictus** | **C. carpio** | **C. spectacularlus** | **M. salmoidies** |
|---|---|---|---|---|
| Copper | 0.27 ± 0.08 | 0.28 ± 0.11 | 0.36 ± 0.11 | 0.31 ± 0.05 |

| | | | | |
|---|---|---|---|---|
| Lead | 1.49 ± 0.10 | 1.56 ± 0.19 | 1.51 ± 0.08 | 3.22 ± 0.15 |
| Zinc | 7.31 ± 0.89 | 8.87 ± 1.1 | 9.32 ± 1.5 | 6.14 ± 0.99 |
| Cadmium | 0.36 ± 0.8 | 0.13 ± 0.05 | 0.44 ± 0.1 | 0.75 ± 0.03 |
| Nickel | 13.62 ± 1.5 | 13.39 ± 1.1 | 14.63 ± 1.5 | 13.18 ± 0.99 |

*Mean ± standard deviation, n = 6*

The data indicates that nickel is the most predominant metal followed by zinc, lead, copper and cadmium respectively. The highest nickel content is found in *C. spectacularlus* followed by*, O. leucostictus C. carpio* and *M. salmoidies i*n that order.

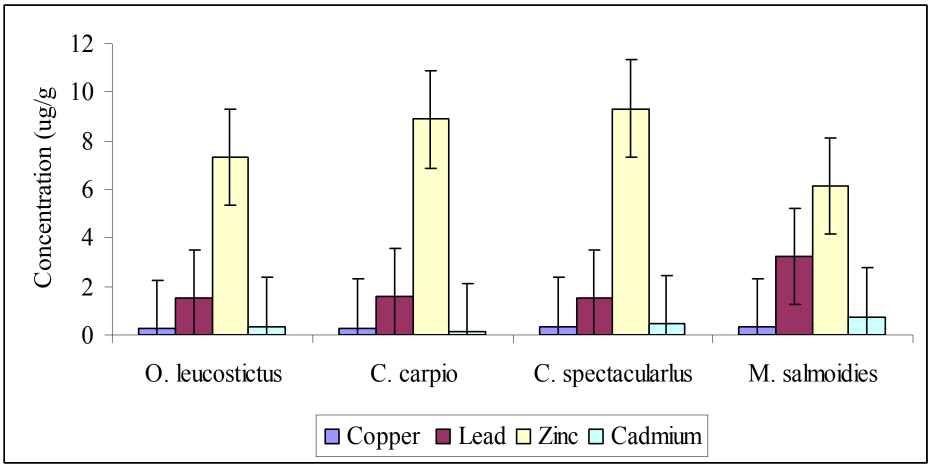


*Figure 4: Bar graph for metal contents in fish*

Zinc is highest in *C. spectacularlus* followed by *C. carpio, O. leucostictus* and *M. salmoidies ,*while lead is highest in *M. salmoidies.* However, the other species have similar lead contents. The study shows that cadmium is in low amounts in the species, the highest cadmium concentrations are found in *M. salmoidies.* The lead and cadmium concentrations in *M. salmoidies* could be due to the trophic position of the fish species in the food web and could be an indicator of bioaccumulation.

Bio-accumulation of metals in the fish species were quantified by a bio-accumulation factor (BAF), which is the ratio of particular metal concentration in the specimen to the concentration of that metal in the water column. The values of bio-accumulation factors were calculated using Equation (1)
BAF = µg per Kg in dry weight / µg per kg in water…………………………………………………………….1

The concentrations of metals in fish were converted to dry weight using the average percent moisture content of 80%, and then converted from µg/g to µg/kg. The mean concentrations of Cu, Pb, Cd, Zn and Ni (µg per kg in water) used in the calculation of BAF were derived from sites inside the main Lake. The BAF values were in the range of 414 – 552 (Cu), 596 – 624 (Pb), 33 – 43 (Zn), 70 – 238 (Cd) and 446 – 487 (Ni). These are low compared to BAF values reported in other studies. This can be explained by the fact that the present study determined total metal content in the water column and most of the metals were not bio-available for accumulation due to adsorption on particulate matter and dissolved carbon. However, the study shows that the bio-concentration of Ni, Cu, Cd and Zn is highest for *C. spectacularus*, accumulation of lead is not different from that shown by *C. carpio*.

## 4.0 Conclusions and Recommendations

The study shows that the lake is polluted with heavy metals, most of which are originating from the lake's catchment area. The most important pollution sources to the Lake Naivasha watercourse are the flower farms, River Malewa and the Naivasha Municipal Council. Based on the chemical composition of samples collected from Sher discharge canal, Oserian Bay, Plantations Plants field, flower farms and the horticultural sector were found to be the most significant source of copper, lead, cadmium and zinc. This is thought to be due to the intensive use of agrochemicals containing heavy metals as active ingredients or contaminants.

River Malewa was found to be an important source of heavy metals. Samples collected from the upper catchment and the point of entry into the lake shows high contents of copper, lead and cadmium. The metals are thought to originate from the farms upstream, downstream and from traffic pollution at the Turasha and Malewa highway bridge. Geochemical processes were also found to add to the metal load due to siltation and soil erosion in the basin, geochemical processes were especially important for nickel and zinc. The Naivasha Municipal Council was also found to be an important source of lead, copper, cadmium and zinc.

Heavy metal concentrations in water and sediments from the lake agree with those reported by Simiyu and Tole (2000), Kubo (2004) and Ochieng' *et al.* (2007) and are lower than those reported by Kisamo (2003) and Kamau *et al.* (2007, 2008). The study reveals that most metals are particulate bound leading to low bioaccumulation factors in fish. There is negative correlation between Secchi depth and heavy metal content. The concentrations fall within the acceptable range of freshwater ecosystems (Alloways and Arynes, 1993) and below the maximum acceptable levels in drinking water (WHO, 1984; CCME, 1991; GOK, 2006).

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