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Selected Heavy Metals in Water and Bottom Sediments in Lake Turkana, Kenya: Distribution and Statistical Analysis

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Abstract

Purpose: Heavy metal pollution in aquatic ecosystems is a threat to health, safe water and food security. Therefore, the study aimed at investigating the quality of Lake Turkana's ecosystem by analyzing levels of lead, cadmium and chromium in water and bottom sediments for necessary interventions.

Methodology: During the dry season, field sampling of water and bottom sediments was performed randomly in triplicates from five locations of Lake Turkana mapped out based on adjacency to potential anthropogenic point pollution sources. Levels of selected heavy metals (lead, cadmium and chromium) were determined using flame atomic absorption spectroscopy (iCE3300 AA System) at Kenyatta University's food science laboratories.

Findings: Water lead, cadmium and chromium ranged: 0.11±0.01 to 0.12±0.00 mg/L, 0.00±0.00 to 0.03±0.00 mg/L and 0.01±0.00 to 0.03±0.01mg/L, respectively while sediment lead, cadmium and chromium ranged: 0.56±0.11 to 1.01±0.03 mg/Kg, 0.02±0.00 to 0.24±0.10 mg/Kg and 0.11±0.03 to 0.20±0.05 mg/Kg, respectively. The lake water contained lead and cadmium beyond WHO allowable limits while sediment lead, cadmium and chromium levels complied with USEPA standards. Lead, cadmium and chromium levels in sediments were significantly higher ($p < 0.05$) than in water in 100 %, 80 % and 60 % of the sites, respectively.

Unique Contribution to Theory, Policy and Practice: The study findings necessitate concerted efforts by researchers, community and policy makers to monitor and control heavy metal levels to ensure water and sediment quality is maintained.

Keywords: *Heavy Metals, Water, Sediments, Lake Turkana, Kenya*

Introduction

In recent years, heavy metal contamination of aquatic ecosystems has become a worldwide concern (UN, 2022). Heavy metals are highly toxic chemical elements with ability to bioaccumulate and bio magnify in the aquatic food chain causing adverse health effects to aquatic life and human when beyond World Health Organization's allowable limits (Kragulj, T., Puric, M., Bursic, V., Vukovic, G., Dokic, M., Puvaca, N. and Petrovic, A., 2018; Briffa, J., Sinagra, E. and Blundel, R., 2020; WHO, 2022). Aquatic heavy metal pollution exacerbates food scarcity by limiting fish productivity (Schindler, D., Stephen, R., Chapra, S., Hecky, R. and Orihel, D., 2016; Kragulj *et al*., 2018; Leung, H., Cheung, K., Chi, A., Young, K. and Wai, C., 2021) and accumulating to unacceptable levels.

Heavy metals detected in the aquatic ecosystem could originate from natural sources but their elevation is influenced by anthropogenic sources such as industries and agriculture (Krantzberg, 2019; Briffa *et al*., 2020; Keyombe, J., Malala, J., Olilo, C., Obiero, M., Bironga, H., Aula, C., Nyamweya, C. and Njiru, J., 2021). The heavy metals infiltrate the ecosystem through direct contact with water or surface runoff during precipitation (Plessl, C., Otachi, E., Körner, W., Avenant-Oldewage, A. and Jirsa, F., 2017; WHO, 2022).The metals not only dissolve in water but also adsorb on the sediments (Mwamburi, 2015; Huang, Z., Liu, C., Zhao, X., Dong, J. and Zheng, B., 2020).

In Lake Turkana, potential anthropogenic heavy metal sources include urban run-off, electronic and plastic waste, oil and lubricant waste (Keyombe *et al*., 2021), chrome tanning (Gebrekidan, A., Gebresellasie G. and Mulugeta, A., 2009), chemical fertilizers and pesticides (Avery, 2010), boat making using synthetic paints and construction of hydroelectric dams (Obiero, K., Wakjira, M., Gownaris, N., Malala, J., Keyombe, J., Ajode, M., Smith, S., Lawrence, T., Ogello, E., Abebe, G. and Kolding, J., 2023). Lead, cadmium and chromium are highly toxic heavy metals. Acute lead poisoning may result in neurological ailments such as paresthesia, abdominal pain, nausea, constipation, diarrhea, cardiovascular, reproductive and kidney problems (Shikha and Tanu, 2016). Chronic exposure is manifested by memory loss, lack of coordination, anemia, slurred speech, numbness and tingling. Lead poisoning may also cause non developmental problems in children (WHO, 2022).

Cadmium is carcinogenic by inhalation route (WHO, 2022). Cadmium poisoning could also cause cardiovascular diseases, osteotoxicity and infertility among other problems such as diarrhea, diabetes and neurological disorders (Honey, S., Neetu, R. and Blessy, B., 2015). Chromium toxicity is dependent on oxidation state with Cr^{+6} exhibiting more toxicity than Cr^{+3} because Cr^{+6} is more soluble, easily reduced and highly mobile in groundwater than Cr^{+3} (Rumpa, S., Rumki, N. and Bidyut, S., 2011). Chromium is carcinogenic to human based on International Agency for Research on Cancer standards (WHO, 2022). Chromium poisoning may also cause renal failure, chronic ulcers, dermatitis and contact hypersensitivity (Rumpa *et al*., 2011).

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The present study analyzed the quantities of lead, cadmium and chromium in water and bottom sediments from Lake Turkana and compared with guidelines by WHO and United States Environmental Protection Agency (USEPA).

Materials and Methods

Study Area

The study site, Lake Turkana is situated in Turkana County, Kenya. According to Malala, J., Obiero, M., Keyombe, J., Olilo, C, Bironga, C., Nyamweya, C., Aura, M. and Njiru, J. (2021), Lake Turkana before swelling was 260.0 km long, 30.0 km in average width, 31.0 m in mean depth, 114.0 m maximum depth and being fed by river Omo (80 % inflow), Turkwel and Kerio. The Lake is found in ASALs with temperature ranging: 24-30°C (Avery, 2010). The selected sampling sites as presented on GPS map (figure 1) were: Napasinyang' River Mouth, Impressa Beach, Long'ech Beach, Lobu Beach and Turkwel/Kerio River Mouth.

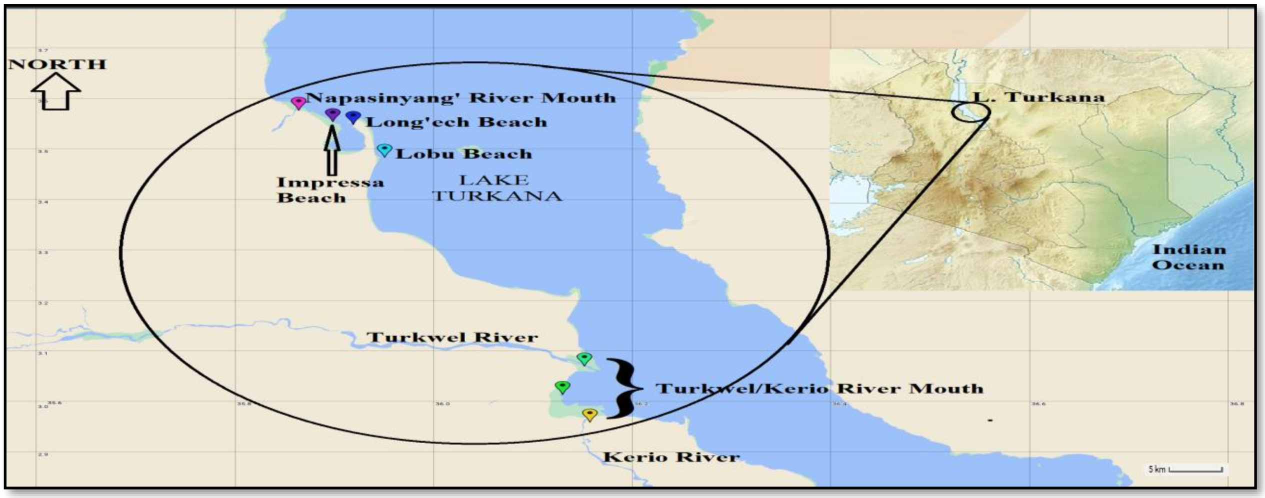

Figure 1: GPS map showing the sampling points in Lake Turkana (Munene, P., Mbugua, G., Wanjau, R. and Ndiritu, N. (2023))

Chemicals and Reagents

Analytical grade conc. HNO_3, con. HCl, Pb $(NO_3)_2$, Cd metal, CrO_3 and distilled water were purchased from Sigma Aldrich.

Sampling and Analysis

Water samples (500.0 mL) were obtained from a depth of 1.0 m using water Nansen bottle method, filtered using 0.45 µm filter, acid preserved and transported to laboratory for analysis. Sediment samples (100.0 g) were collected using sediment grabber and ice preserved at 4 °C. Field sampling was performed randomly in triplicates and lead, cadmium and chromium determined in a laboratory using flame atomic absorption spectroscopy (iCE3300 AA System).

Data Analysis

Data was presented as Mean ± Standard Error of Mean. One-way Analysis of Variance (one-way ANOVA) was used to compare heavy metals between sampling locations while Student's t test analyzed levels between water and sediments. All the means with a P value ≤ 0.05 were considered.

Results and Discussion

The heavy metal levels in Lake Turkana's water are summarized in table 1. The results in table 1 showed that water lead levels ranged: 0.11±0.01 to 0.12±0.00 mg/L. Lobu Beach and Turkwel/Kerio River Mouth had the highest lead levels of 0.12±0.00 mg/L could be due to fossil fuel residues from transportation activities (Carr, 2017) at Lobu Beach and urban and agricultural run-off in Turkwel and Kerio rivers (Avery, 2010). The lead levels in water surpassed WHO guideline value of 0.01 mg/L in all sampling locations.

The cadmium levels in table 1 fell in the range: 0.00±0.00 to 0.03±0.00 mg/L. The Long'ech Beach had the highest cadmium level of 0.03±0.00 mg/L which could have been caused by assorted wastes from the Long'ech settlements (Keyombe *et al.*, 2021). The cadmium levels in Impressa and Long'ech beaches exceeded WHO guideline value of 0.003 mg/L.

From table 1, it was also observed that the chromium levels fell in the range: 0.01±0.00 to 0.03±0.01mg/L. The Long'ech Beach recorded the highest chromium level of 0.03±0.01mg/L could be due to fossil fuel residues from transportation activities (Alloway, 2013). However, the chromium levels in all locations complied with WHO standard of 0.05 mg/L and was in the range of previous studies.

The heavy metal levels in Lake Turkana's sediments are summarized in table 2. From table 2, it was observed that the lead level in sediments was ranging from 0.56±0.11 to 1.01±0.03 mg/Kg. The lead detected in sediments could be due to deposition and adsorption on the sediment particles that have a large surface area (Onjef, S., Kgabi, N. and Taole, S., 2016; Luo, M., Yu, H., Liu, Q., Lan, W., Ye, Q., Niu, Y. and Niu, Y., 2021). The results also show that the Napasinyang' River Mouth had the highest lead level of 1.01±0.03 mg/Kg and this could be caused by urban wastes in the stream (Avery, 2010) while Lobu Beach had the lowest lead levels of 0.56±0.11 mg/Kg probably due to location far from direct influence by anthropogenic activities (Keyombe *et al.*, 2021). The sediment lead levels in all locations of Lake Turkana complied with USEPA standard of <40.0 mg/Kg, indicating that the sediments could not pollute the water column and benthic organisms (Mwamburi, 2015; Huang *et al.*, 2020).

The recorded lead levels were appreciably lower than 60.23±2.21 mg/Kg reported in Lake Naivasha by Njogu, P., Keriko, J., Wanjau, R. and Kitetu, J. (2011) and 11.89 mg/Kg by Mavura and Wangila (2003) in Lake Nakuru within the same Rift Valley zone.

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Table 1: Mean heavy metal levels in Lake Turkana's water vs WHO

Sampling Sites		Napasinyang' River Mouth	Impressa Beach	Long'ech Beach	Lobu Beach	Turkwel/ Kerio River Mouth	WHO
Concentration of Heavy Metals Mean ± SEM (mg/L)	Pb	0.11±0.01[a]	0.11±0.01[a]	0.11±0.01[a]	0.12±0.00[a]	0.12±0.00[a]	0.01
	Cd	0.00±0.00[c]	0.02±0.00[b]	0.03±0.00[a]	0.00±0.00[c]	0.00±0.00[c]	0.003
	Cr	0.02±0.01[a]	0.01±0.00[a]	0.03±0.01[a]	0.02±0.01[a]	0.01±0.01[a]	0.05

Data is expressed as Mean ± SEM, n=3. Values with similar lowercase superscript row-wise are not significantly different (p > 0.05)

Table 2: Mean heavy metal levels in Lake Turkana's bottom sediments vs USEPA

Sampling Sites		Napasinyang' River Mouth	Impressa Beach	Long'ech Beach	Lobu Beach	Turkwel/ Kerio River Mouth	USEPA
Concentration of Heavy Metal Mean ± SEM (mg/Kg)	Pb	1.01± 0.03[a]	0.92± 0.14[a]	0.77± 0.19[a]	0.56± 0.11[a]	0.79± 0.21[a]	< 40.0
	Cd	0.06± 0.01[a]	0.24± 0.10[a]	0.22± 0.05[a]	0.02± 0.00[a]	0.08± 0.02[a]	< 6.0
	Cr	0.19± 0.03[a]	0.20± 0.05[a]	0.17± 0.08[a]	0.13± 0.03[a]	0.11± 0.03[a]	< 25.0

Data is presented as Mean ± SEM, n=3. Values with similar lowercase superscript row-wise are not significantly different (p > 0.05)

As indicated in table 2, it was observed that the sediment cadmium level fell in the range of 0.02±0.00 to 0.24±0.10 mg/Kg. Cadmium was detected in the bottom lake sediments and this could be due to deposition and adsorption processes on sediment particles (Onjef *et al*., 2016; Luo *et al*., 2021). In addition, Impressa Beach had the highest sediment cadmium concentration of 0.24±0.10

mg/Kg and this could be due to transportation activities (Carr, 2017) while the Lobu Beach had the lowest sediment cadmium concentration of 0.02±0.00 mg/Kg which could be due to location far from human activities (Keyombe *et al*., 2021). The sediment cadmium level in all locations also complied with USEPA limit of <6.0 mg/Kg, indicating that the sediments were unpolluted and favourable for the sediment-living organisms (Mwamburi, 2015; Huang *et al.*, 2020). Higher levels of cadmium in Impressa Beach could be due to fossil fuel residues from transportation activities (Carr, 2017). This was consistent with the results recorded by Otachi, E., Plessl, C., Körner, W., Avenant-Oldewage, A. and Jirsa, F. (2015) in sediment trace elements analysis.

From table 2, it was observed that chromium level ranged: 0.11±0.03 to 0.20±0.05 mg/Kg. The chromium detected in the sediments could be due to deposition and adsorption on sediment particles (Onjef *et al*., 2016; Luo *et al*., 2021). The highest chromium level was recorded at Impressa Beach and this could be due to fossil fuel residues from transportation activities (Carr, 2017) while the lowest chromium level was reported at Turkwel/Kerio River Mouth could be due to location far from River Omo's influxes (Gebrekidan *et al.*, 2009).The chromium level in all locations complied with USEPA limit of <25.0 mg/Kg, indicating that they was not polluted (Mwamburi, 2015, Huang *et al.*, 2020). The findings were in agreement with the study by Mwamburi. (2016) at Lake Victoria that reported higher sediment chromium levels in the range of 23.04±8.95 to 62.26±33.47 mg/Kg. Mavura and Wangila (2003) also reported a higher sediment chromium level of 3.19 mg/Kg in Lake Nakuru and also linked it to unmanaged industrial pollution near Lake Nakuru.

Comparison of Heavy Metal Levels between Water and Bottom Sediments

The statistical comparison of lead levels between the water and sediments is presented on table 3.

Table 3: Mean lead levels between water and sediments

Sampling Site	Water Sample (mg/L)	Sediment Sample (mg/Kg)
Impressa Beach	$0.11±0.01^{aA}$	$0.92±0.14^{aB}$
Lobu Beach	$0.12±0.00^{aA}$	$0.56±0.11^{aB}$
Longe'ch Beach	$0.11±0.01^{aA}$	$0.77±0.19^{aB}$
Napasinyang' River Mouth	$0.11±0.01^{aA}$	$1.01±0.03^{aB}$
Turkwel/Kerio River Mouth	$0.12±0.00^{aA}$	$0.79±0.21^{aB}$

Data is presented as Mean ± SEM n=3. Values with similar lowercase superscript column-wise are not significantly different. Values with similar uppercase superscript row-wise are not significantly different (p > 0.05)

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From table 3, it was observed that lead levels in both water and sediments were not significantly different ($p > 0.05$) in all the sampling points.

However, the lead levels in sediments were significantly higher ($p < 0.05$) than in water could be due to deposition and adsorption of lead on the sediment particles that have a large surface area (Onjef *et al*., 2016; Luo *et al*., 2021).The high lead levels in water could also be due to release of lead ions from the sediments accelerated by the high lake temperature (Li, H., Shi, A., Li, M. and Zhang, X., 2013).The statistical comparison of cadmium levels between the water and sediments is presented on table 4.

Table 4: Mean cadmium levels between water and sediments

Sampling Site	Water Sample (mg/L)	Sediment Sample (mg/Kg)
Impressa Beach	0.02 ± 0.00^{bA}	0.24 ± 0.10^{aA}
Lobu Beach	0.00 ± 0.00^{cA}	0.02 ± 0.00^{aB}
Longe'ch Beach	0.03 ± 0.00^{aA}	0.22 ± 0.05^{aB}
Napasinyang' River Mouth	0.00 ± 0.00^{cA}	0.06 ± 0.01^{aB}
Turkwel/Kerio River Mouth	0.00 ± 0.00^{cA}	0.08 ± 0.02^{aB}

Data is expressed as Mean ± SEM n=3. Values with similar lowercase superscript column-wise are not significantly different. Values with similar uppercase superscript row-wise are not significantly different ($p > 0.05$)

From table 4, it was discovered that the cadmium levels were significantly higher ($p < 0.05$) in water from Impressa beach (0.02±0.00 mg/L) and Long'ech Beach (0.03±0.00 mg/L) than in all other sampling points could be due to assorted wastes from the Kalokol and Long'ech settlements (Keyombe *et al*., 2021). It was also observed that cadmium levels in sediments were not significantly different ($p > 0.05$) in all the sampling points. However, the cadmium levels in sediments from Lobu Beach, Long'ech Beach, Napasinyang' River Mouth and Turkwel/Kerio River Mouth were significantly higher ($p < 0.05$) than in water samples from the sampling sites could be due to deposition and adsorption processes on sediment particles (Onjef *et al*., 2016; Luo *et al*., 2021). The statistical comparison of chromium levels between the water and sediments is presented on table 5.

Table 5: Mean chromium levels between water and sediments

Sampling Site	Water Sample (mg/L)	Sediment Sample (mg/Kg)
Impressa Beach	0.01 ± 0.00^{aA}	0.20 ± 0.05^{aB}
Lobu Beach	0.02 ± 0.01^{aA}	0.13 ± 0.03^{aB}
Longe'ch Beach	0.03 ± 0.01^{aA}	0.17 ± 0.08^{aA}
Napasinyang' River Mouth	0.02 ± 0.01^{aA}	0.19 ± 0.03^{aB}
Turkwel/Kerio River Mouth	0.01 ± 0.01^{aA}	0.11 ± 0.03^{aA}

Data is presented as Mean ± SEM n=3. Values with similar lowercase superscript column-wise are not significantly different. Values with similar uppercase superscript row-wise are not significantly different ($p > 0.05$).

From table 5, it was observed that chromium levels in water and sediments from Long'ech Beach and Turkwel/Kerio River Mouth were not significantly different ($p > 0.05$) could be due to diffusion of chromium between water and sediments (Mwamburi, 2015; Huang *et al.*, 2020). However, the chromium levels in sediments from Impressa Beach, Lobu Beach and Napasinyang' River Mouth were significantly higher ($p < 0.05$) than in water from the sampling sites could be due to strong adsorption of chromium on sediment particles (Onjef *et al*., 2016; Luo *et al*., 2021).

Conclusion

The study established lead and cadmium in water to be beyond WHO allowable levels. However the three heavy metals in sediments complied with USEPA standards indicating that the sediments were unpolluted. The study also observed that lead, cadmium and chromium were strongly adsorbed on sediments in 100 %, 80 % and 60 % of the sites, respectively. The study provided insight into heavy metal pollution and control of Lake Turkana.

Recommendations

There is need to monitor heavy metal levels, create community awareness on pollution causes, effects and prevention, and tailor policies to control heavy metal levels in Lake Turkana's ecosystem. Further analysis involving fish, other heavy metals, pharmaceutical residues and pesticides is highly recommended.

Conflicts of Interest

The author declares no potential conflict of interest.

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