Determination of Heavy Metals in Nairobi Dam Water, (Kenya)

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Abstract: *Heavy metals concentrations in Nairobi dam water were analysed between the wet and dry seasons. Water samples were collected once in a month from seven sampling sites within Nairobi dam, these samples were preserved, stored and analysed for heavy metals: Copper (Cu), Cadmium (Cd), Lead (Pb) and Nickel (Ni) concentrations using an Atomic Absorption Spectrophotometer (APHA). The sequence of heavy metals accumulation in dam's water was: Pb > Cd > Cu > Ni, these metals mean values during the dry vs. wet seasons were: 16.78±0.21 vs 11.67±0.21; 5.12±0.18 vs 3.76±0.15; 4.90±0.25 vs 2.99±0.05; 2.11±0.12 vs 1.20±0.13mg/L respectively within water of Nairobi dam. These levels of heavy metals in this dam are higher than maximum permissible levels by WHO, EU and KEBS for drinking water. The outlet water had significantly lower metals contamination in comparison to the inlet waters of the dam (p≤0.006) during the wet than dry season. It is concluded that higher levels of heavy metals concentration in the dam`s water is in the dry than wet season (p<0.0001). Based on water analysis data it is recommended that the water of this dam is not suitable for human consumption and even for agricultural activities.*
Keywords: *Water, Heavy metals, Nairobi dam*

I. Introduction

Contamination of heavy metals in surface water systems may be either due to natural or anthropogenic activities. The discharge of toxic heavy metals in water bodies is a serious pollution problem affecting water quality especially in wetlands and other water masses due to their toxicity and bio accumulative effect, creating a direct hazard to human health [1]. Heavy metals pollutants in surface water may pose a health risk and can be very harmful if present in drinking water and translocated to food chains. These metals disturb growth, development, reduce haemoglobin, create cancer, damage the body organs and the nervous system, and in extreme cases death of living organisms [2,3].

All heavy metals exist in surface waters in colloidal, particulate, and dissolved phases, although dissolved concentrations are generally low [4]. The solubility of trace metals in surface waters is predominately controlled by the water pH, the type and level of ligands on which the metal could adsorb, and the oxidation state of the mineral components and the redox environment of the system [5].

An assessment of heavy metals concentrations in the surface water of Bompai-jakara drainage basin, Kano State, northern Nigeria, revealed that the annual levels of Cr>Fe>Zn>Cu>Pb during the dry than wet seasons but were not statistically significant at P≥0.05. All these five elements analyzed had concentrations above WHO and American Water Works Association standard limit for effluents discharge into surface waters [6]. It has been reported that the differences in geography and geologies, as well as activities in various rivers affects the amount of metals present [7,8]. "Heavy metals cannot be degraded they are continuously being deposited and incorporated in water, sediments and aquatic organisms." [9]

The purpose of this study was to analyse the levels of heavy metals in water, and to monitor the water quality of Nairobi dam (Kenya) during wet and dry seasons. Kibera is the largest slum dwellings in Africa on the North eastern bank of Nairobi dam (Kenya). It is an informal settlement by all standards, and a major contributor to pollution of the Motoine-Ngong river (Fig. 1) mostly due to large quantities of waste emanating from unserviced households, solid and liquid waste, including human waste dumped into trenches that drain into the river, and flows into Nairobi Dam [10]. This results to bio-concentrations and biomagnifications which causes potential ecological imbalances and direct health hazards to local people who depend on the water and products from the resource; and especially residents of Kibera informal settlement adjacent to the dam, who are utilizing water from this resource for domestic and commercial purposes.

II. Materials And Methods

Study Area

The study was carried out at Nairobi dam, in Nairobi, Kenya (Fig. 1). The dam is situated at a latitude of 1° 19' (1.3167°) south; longitude of 36° 48' (36.8°) east and has an average elevation of 1,686 meters (5,531 feet) above the sea level. The capacity of this dam is 98,422 cu. metres of water and it covers surface area of about 356,179m^2
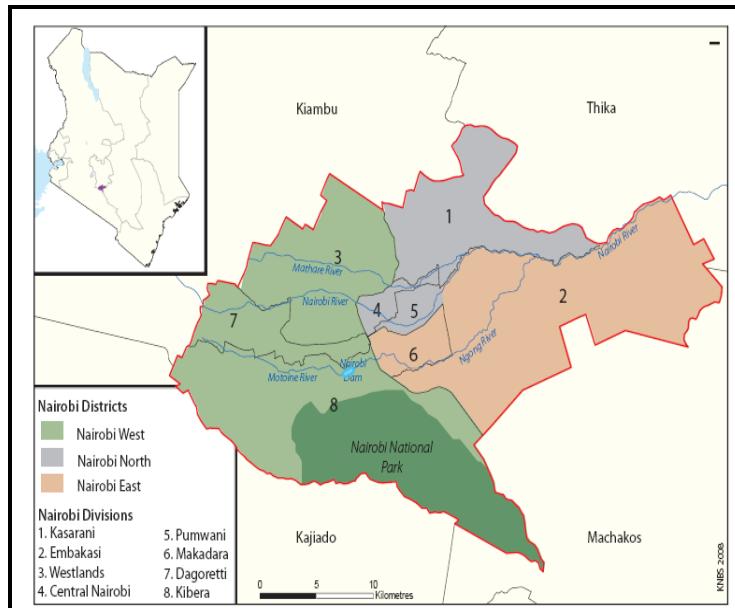
Figure 1: Map of Kenya showing study area i.e. Nairobi Dam

III. Data Collection and Analysis

The samples of water from inlet, outlet and also from within the dam were collected from seven sampling stations (n=7): (1st sample station was 10m before the stream dropping in Nairobi dam; 2nd station was at a distance of 5m after the discharge; 3rd station was 5m inwards of the west shore; 4th station was 5m inwards of the outlet, 5th station was 5m inwards of the east shore; 6th station was approximately in the centre of the dam, and the 7th station was 1m from the outlet stream of Nairobi dam). Clean labelled polypropylene plastic bottles [11] were used to collect samples. Water samples were collected once in a month from a depth of 0.5m from the surface of the selected seven stations, during the wet season (November 2012 to early January 2013) and during the dry season (February to early April 2013). These water samples were transported to chemical laboratory and preserved with 1.5ml/L analar Conc. HNO_3. The water samples were digested in Conc.$3HNO_3$:HCl [11]. Shimadzu flame Atomic Absorption spectrophotometer (AA-630) was used in the determinations of heavy metals (Pb, Cu, Cd, Ni) [11]. Data analysis includes statistical summaries (mean and standard error values at each sampling site, from 1 to 7; and independent T-test at α=0.05).

IV. Results And Discussion

Heavy Metals Concentrations in Nairobi Dam Water During Wet and Dry Seasons

Analysis of dam's water showed that higher concentrations of Cu, Cd, Pb and Ni were in the dry season with mean values of 4.90, 5.12, 16.78 and 2.11mg/L as compared to the wet season mean values of 2.99, 3.76, 11.67 and 1.20mg/L respectively (Fig. 2). This was due to increase in temperature and high rate of evaporation during the dry season, resulting to high concentrations of these heavy metals in the dam water. The rainy (wet) season caused a dilution factor in the water body, therefore, low concentrations of these heavy metals were recorded in the dam's water.

Similar results were obtained by Nairobi River Basin Project–Phase II, [12] that the wet weather metal ions concentrations in rivers water were low as compared to dry season levels due to dilution from increased river flow from surface run-off. A study on heavy metals in water at a freshwater wetland in Central Gujarat, India concluded that higher levels of Cd, As and Pb were in water during the dry compared to wet season, due to high rates of evaporation of water during pre monsoon, however after heavy rainstorm their concentrations reduced [13].

It was evident from the results (Fig. 2) that the order of heavy metals concentrations was Pb > Cd > Cu > Ni. Lead (Pb) concentrations in the samples were approximately three times the concentration of Cd and Cu and about eight times those of Ni. The concentrations of Cd in the samples were slightly higher than those of Cu in both seasons. This suggests that Nairobi dam environs are contaminated with these heavy metals in the order: Pb > Cd > Cu > Ni. Several observed socio-economic and waste dumping activities upstream and from Kibera slums adjacent to the dam includes agriculture, car garages, industries, construction works, car washing, human waste, raw sewage and garbage which are major sources of heavy metal accumulations in the dam.
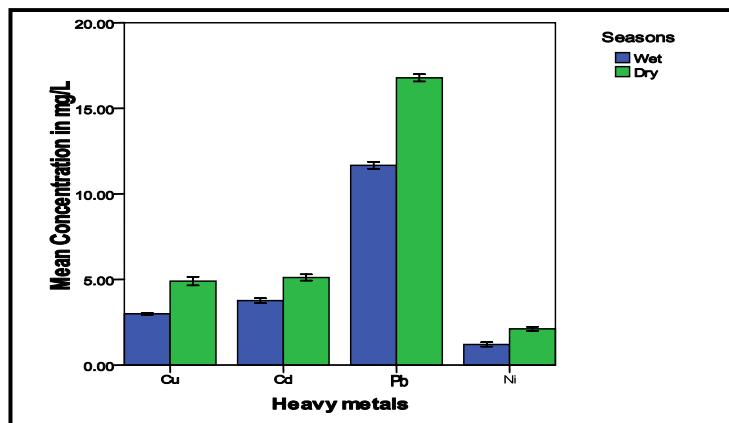
Figure 2: Heavy metals concentrations in the water of Nairobi dam, Kenya

Analysis of heavy metals in water of Madivala Lakes of Bangalore, Karnataka state of India revealed that the order of levels of heavy metals were: Pb > Cr > Cd > Ni in the water's of the lake [14]. Assessment of heavy metals pollution in water in the northern delta lakes, Egypt [15] showed that metals concentrations in water were in the order: Fe > Mn > Pb > Zn > Cu > Cd in Lake Edku, whereas the order was: Fe > Mn > Pb > Zn > Cu > Cd in Lake Borollus and in Lake Manzala, metals were in the order: Fe > Mn = Cu > Zn > Pb > Cd. The sequences of metals concentrations in the three Lakes were: Fe > Mn > Cu > Zn > Pb > Cd.

Variations of Heavy Metal(s) in Water at Different Sampling Sites Within Nairobi Dam During Wet and Dry Seasons

From the results presented in Table 1, during the wet season the dam's water had the highest levels of Cu, Cd, Pb and Ni at site 5 (3.18mg/L), site 1 (4.61mg/L), site 3 (12.35mg/L) and site 3 (1.79mg/L) respectively. However, in the wet season the lowest level of Cu was at site 4 (2.62mg/L), while those of Cd, Pb and Ni were in site 7 at (2.89mg/L), (10.16mg/L) and (0.28mg/L) respectively. During the dry season (Table 1) maximum levels of Cu, Cd, Pb and Ni in dam's water were at site 3 (5.72mg/L), site 1 (6.18mg/L), site 3 (17.51mg/L) and site 1 (2.65mg/L) respectively. Minimum level of Cd was at site 4 (4.04mg/L), whereas those of Cu, Pb and Ni were at site 7 (3.10mg/L, 15.22mg/L and 1.11mg/L) respectively. There were reduced levels of all the heavy metals in site 2 compared to site 1, for instance during the wet season Cu level at site 2 was 2.95mg/L against 3.07mg/L at site 1. Higher levels of heavy metals were in site 3 compared to site 6 during wet and dry seasons.

These results suggest that high levels of heavy metals pollution in dam's water were at site 1, 3 and 5 while reduced levels were in site 4 and 7. This may be due to large quantities of solid and liquid waste disposed in the dam from Kibera slum adjacent to site 3 and the activities including garages, carwash, agriculture and sewage flowing into the dam along site 1 and 5. Reduced levels of these heavy metals near the outlet and at the outlet (site 4 and 7) may be due to pollution removal mechanisms within the wetland. There were significant differences ($p < 0.05$) in heavy metal's (Cu, Cd, Pb and Ni) accumulation in dam's water within the different sampling sites 1 to 7 during the wet and dry seasons (Table 1). This may be attributed to varying human activities and ecological characteristics at different sampling sites.

Speciation of heavy metals in water of Asunle River, Nigeria [16] revealed that total heavy metals concentrations in water from different sampling sites within the river varied, mean Zn, Pb, Cu, Co, Cd and Ni levels were (1.35, 0.03, 1.10, 0.05, 0.02 and $0.22 \mu g/mL$) in site O; (2.96, 0.07, 2.68, 0.10, 0.06 and $0.55 \mu g/mL$) in site A; (2.35, 0.06, 2.35, 0.08, 0.05 and $0.44 \mu g/mL$) in site B; (1.98, 0.05, 2.00, 0.08, 0.04 and $0.33 \mu g/mL$) in site C; (1.68, 0.05, 1.68, 0,07, 0.03 and $0.30 \mu g/mL$) in site D respectively. Site O reflected the least levels of heavy metals while A had the highest levels indicating a direct input of heavy metals from the dumpsite. Also, there was a general decrease in the levels of total metals downstream from A to D.

In all the seven sampling sites (n=7) (Table 1), levels of heavy metals (Cu, Cd, Pb, Ni) were significantly higher in dry than wet season ($p \leq 0.042$). The overall mean of Cu, Cd, Pb and Ni concentrations in dam's water were significantly higher in dry than wet season ($p < 0.0001$). This is due to high evaporation rate during the dry season which resulted to higher concentrations of heavy metals in dam's water compared to dilution in wet season. A study on heavy metals in water in an aquatic ecosystem of tropical industrial region, (India) [17] concluded that comparatively low value for all metals were recorded during rainy season compared to summer, which is due to dilution by addition of rain water and subsequent outflow of reservoir water. Analysis of heavy metals in water of lower River Niger in North Central Nigeria, [18] attributed the high levels of Zn, Cr, Cu, Mn and Ni in rivers water during dry than wet season to be due to decrease in the rivers water in the dry season resulting to increase in concentration of the metals in water.

Table 1: Analysis of heavy metal(s) concentrations in Nairobi dam water collected from seven sampling sites in wet and dry seasons

Heavy metal(s)	Sampling Site(s)	Wet season (Mean ±SE) mg/L	Dry season (Mean ±SE) mg/L	p-value
Cu	1	3.07±0.06	5.55±0.14	<0.0001
	2	2.95±0.07	5.36±0.12	<0.0001
	3	3.17±0.12	5.72±0.32	0.002
	4	2.62±0.09	3.33±0.12	0.010
	5	3.18±0.09	5.66±0.23	0.001
	6	3.10±0.08	5.59±0.29	0.001
	7	2.82±0.13	3.10±0.09	0.040
	Mean	2.99±0.05	4.90±0.25	<0.0001
Cd	1	4.61±0.25	6.18±0.20	0.008
	2	4.41±0.24	6.00±0.22	0.008
	3	4.12±0.13	5.23±0.09	0.002
	4	3.23±0.16	4.04±0.09	0.012
	5	3.59±0.26	5.13±0.08	0.005
	6	3.48±0.22	5.10±0.07	0.002
	7	2.89±0.12	4.12±0.33	0.024
	Mean	3.76±0.15	5.12±0.18	<0.0001
Pb	1	12.12±0.14	17.19±0.13	<0.0001
	2	12.24±0.14	17.31±0.16	<0.0001
	3	12.35±0.15	17.51±0.11	<0.0001
	4	10.35±0.12	15.43±0.10	<0.0001
	5	12.23±0.14	17.38±0.12	<0.0001
	6	12.23±0.13	17.44±0.10	<0.0001
	7	10.16±0.10	15.22±0.10	<0.0001
	Mean	11.67±0.20	16.78±0.21	<0.0001
Ni	1	1.60±0.20	2.65±0.15	0.014
	2	1.39±0.19	2.47±0.20	0.018
	3	1.79±0.10	2.31±0.12	0.029
	4	0.57±0.16	1.71±0.16	0.008
	5	1.51±0.27	2.39±0.12	0.042
	6	1.26±0.12	2.16±0.11	0.005
	7	0.28±0.15	1.11±0.23	0.038
	Mean	1.20±0.13	2.11±0.12	<0.0001

Mean ±SE value with $p<0.05$ are significantly different ($\alpha=0.05$, independent T-test)

In all the sampling sites (n=7) (Table 1) during both the wet and dry seasons, the levels of heavy metals Cu, Cd, Pb and Ni in Nairobi dam are in excess of tolerable levels for drinking water based on WHO; EU; and KEBS [3,19,20] standards (Appendix I). Similar results were reported on assessment of the water quality status of Sasumua Watershed, (Kenya) which revealed that for both dry and wet seasons most parameters analysed at Ming'utio River were above WHO standards. Exaggerated levels of potassium, iron, lead, manganese, pH and turbidity were found; the levels of Fe, Pb, Mn in the wet season were 1.84; 0.06; 0.87 mg/L vs. those in dry season of 18.46; 0.23; and 4.00 mg/L, respectively [21].

A study on heavy metal concentrations in water samples around tejgaon industrial area of (Bangladesh) showed that heavy metals concentrations at different sampling points varied in different seasons and the maximum amounts were observed in the dry season. Total Fe, Pb, Cd, Mn, Ni, Zn, Cu and Cr concentrations in water samples during dry season ranged from 0.11 - 2.78, 0.733 - 2.171, 0.05 - 0.1, 0.019 - 0.34, 0.02 - 0.17, 0.01 - 0.348, 0.10 - 0.846, and 0.02 - 0.09 mg/L respectively [22]. It was also noted that according to WHO guidelines, during both wet and dry seasons, 100% water samples were found in the group of "in excess of tolerable level" for Pb and 95% water samples were found in the group of 'in excess of tolerable level' for Cu, Ni, Cd, Cr and Mn during dry season [22].

Levels of Heavy Metals Variations in the Inlet and Outlet Water of Nairobi Dam During Wet and Dry Seasons

Table 2 shows that during the wet season the levels of Cu, Cd, Pb, Ni in the inlet vs. outlet water of the dam were 3.07 vs 2.82, 4.61 vs 2.89, 12.12 vs. 10.16, 1.60 vs 0.28mg/L respectively. In the dry season these heavy metals levels within the inlet vs. outlet water were 5.55 vs 3.10, 6.18 vs 4.12, 17.19 vs 15.22, 2.65 vs 1.11mg/L respectively. This shows that during both wet and dry seasons the levels of heavy metals were lower in the outlet water compared to the inlet water of the dam. Therefore, this dam has heavy metals retention capability. A toxicological evaluation that employed an in situ chironomus bioassay at the inlet and outlet of a constructed wetland in South Africa revealed 89% reduction in toxicity [23]. Similar findings were reported by Schiffer [24] that 26 of 40 water quality variables, such as Al, Pb and Zn, were significantly different between the inlet, outlet, near, intermediate, and far sites (with respect to the inlet) of the wetland; these contaminations reduced with distance from the inlet. Heavy metals accumulated in the inlet and outlet water in the order: Pb > Cd > Cu > Ni in wet and dry seasons (Table 2). This suggests the sequence of heavy metals contamination in the dam's inlet and outlet waters. It also indicates that Pb is the highest and Ni lowest retained metal in the wetland.

Table 2: Comparison of heavy metal's concentrations in the inlet and outlet waters of Nairobi dam during wet and dry seasons

Parameter	Season(s)	Inlet (Mean ±SE)mg/L	Outlet (Mean ±SE)mg/L	p-value
Cu	Wet	3.07±0.06	2.82±0.13	0.167
	Dry	5.55±0.14	3.10±0.09	<0.0001
Cd	Wet	4.61±0.25	2.89±0.12	0.004
	Dry	6.18± 0.20	4.12±0.33	0.006
Pb	Wet	12.12±0.14	10.16±0.18	<0.0001
	Dry	17.19±0.13	15.22±0.10	<0.0001
Ni	Wet	1.60±0.20	0.28±0.15	0.006
	Dry	2.65±0.15	1.11±0.23	0.005

Mean ±SE value with $p<0.05$ are significantly different ($\alpha=0.05$, independent T-test)

The levels of Cu, Cd, Pb and Ni were significantly higher in the outlet than inlet water of the dam during both wet and dry seasons ($p\leq0.006$) except for Cu during the wet season (Table 2). This may be attributed to bio accumulations and deposition of heavy metals on bottom sediments of this wetland. Ndeda [25] also studied accumulation of heavy metals in hydrophytes and sediment of Nairobi dam and revealed that heavy metals accumulate in sediments and hydrophytes within wetlands.

V.   Conclusion

The range of heavy metal(s) accumulation in dam's water within all the seven sampling sites were $0.28\pm0.15 – 17.51\pm0.11$mg/L. The sequence of metals accumulation was Pb > Cd > Cu > Ni, which were significantly higher in Nairobi dam water ($p<0.0001$) during the dry compared to wet season. This shows that the dry season gives the worst case scenario of pollution. There was significant reduction ($p\leq0.006$) of heavy metal(s) contaminations in the outlet water as compared to inlet waters in the wet than dry season. This indicates that pollution removal mechanisms takes place in water bodies. Based on WHO; EU and KEBS [3,19,20] standards for drinking water, Nairobi dam water is highly polluted by Pb, Cd, Cu and Ni. Therefore, the water is not good for human and animal drinking and also for any agricultural activities.

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Appendix I: Maximum permissible levels of heavy metals in drinking water according to WHO, EU and KEBS Standards

	Copper	Cadmium	Lead	Ni
WHO(2011)	2 mg/L	0.003 mg/L	0.01 mg/L	0.07 mg/L
EU (1998)	2 mg/L	0.005 mg/L	0.01 mg/L	0.02 mg/L
KEBS(2007)	1 mg/L	0.003 mg/L	0.01 mg/L	0.02 mg/L
Study results	3.95 mg/L	4.44 mg/L	12.69mg/L	1.66 mg/L