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Research Article

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Recent Influences of Anthropogenic Activities and Seasons on Heavy Metal Distribution in Shoreline Sediments in Lake Victoria Near Kisumu City, Kenya

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Abstract

The Winam Gulf on Lake Victoria around Kisumu city has seen increase in anthropogenic activities. The activities discharge pollutants, especially heavy metals into the lake. The heavy metals sink into sediments, which slowly release them into the lake water. The objective of this study was to evaluate the distribution and sources of heavy metals into Winam Gulf sediments near Kisumu city during wet and dry seasons. Sediments were sampled from sites at Molasses Plant, Coca-Cola Plant, Rivers Kisat and Kisian discharge points at intervals of 50 m from the shoreline into the lake. The metal level (µg/g) ranges obtained were: 0.90-1.20 (Cd), 2.60-36.00 (Cr), 71.40-122.90 (Cu), 1283.40-1468.70 (Fe), 792.30-1631.20 (Mn), 61.80-181.00 (Pb) and 100.10-187.60 (Zn) with River Kisat discharge point recording the highest levels for all metals. The metal levels were different ($p \leq 0.05$) in all sites. River Kisat discharge point had the highest heavy metals concentration due to the dense anthropogenic activities within the adjacent environment. Metal levels varied ($p \leq 0.05$) with seasons in all sites with higher levels recorded during wet season an indication of surface runoff. In all sites, the levels decreased ($p \leq 0.05$) with increased distances from the shore into the lake suggesting a dilution effect. The results confirm that the anthropogenic activities cause metal pollution. It is necessary to control activities that discharge heavy metals into the lake water and continuously monitor the heavy metal levels. This will enable enforcement agencies to formulate regulations to safeguard human and aquatic life within the gulf.

Keywords: Anthropogenic activities; Heavy metals; Sediments; Winam gulf; Kisumu city; Kenya

Introduction

Water bodies are the ultimate recipients of anthropogenic discharges. Sediments are sinks for pollutants including heavy metals and play key roles in the availability of heavy metals in aquatic ecosystems [1-3]. Consequently, sediments can be indicators in mapping out hot spots of heavy metal pollution caused by anthropogenic activities within adjacent environments [4]. Lake Victoria has a large surface area of 68,800 Km^2 [5] and is surrounded by urban centers with different anthropogenic activities and the region has varying geochemical makeup that may cause differences in heavy metals concentrations in sediments [2]. Pb, Cd, Cr, Cu, Mn, Zn and Fe are aquatic ecosystem pollutants that can enter the food chains. However, in optimal doses some of these heavy metals aid metabolism [6]. Maintaining healthy lake ecosystem is therefore a challenge to regulatory agencies.

In the 1980s, heavy metal pollution was very low in sediments from Winam Gulf shoreline near Kisumu city [7,8]. Recent studies recorded an increase in levels of heavy metals in sediments within the same region [9-12] This was due to increase in anthropogenic activities, especially population growth, urbanization, agricultural activities, pharmaceutical discharges, industrial processes, and municipal waste discharges [12,13] This trend suggests that the lake water is probably continuously being polluted as the sediments absorb more heavy metals. The shoreline of Winam Gulf near Kisumu has several anthropogenic activities. However, the variations in heavy metals concentrations in sediments along the lake shoreline near Kisumu city at different points are not documented.

Studies on heavy metal concentrations in water and sediments in rivers draining into Winam Gulf of Lake Victoria revealed that Cd, Pb, Zn, Cr, Cu and Mn levels were higher than the WHO and Shale Standards set limits and the levels were attributed to anthropogenic activities [14]. The metals through sorption-desorption processes end up in the lake water mass and ultimately in bed sediments. Other possible sources of heavy metals include domestic discharges, water and road traffic. In the previous studies [8,12] water and sediments sampling were randomly done without matching sampling point to specific anthropogenic activities. Kisumu city has experienced recent intense urban expansion resulting in increase in anthropogenic activities. From River Kisat discharge point to River Kisian discharge point in Kisumu city, several anthropogenic activities are taking place. Results of a study evaluated influence of the specific activities on heavy metal concentrations in sediments are reported.

Materials and Methods

The study was carried out along the shoreline of Winam Gulf in Lake Victoria near Kisumu city within latitudes 00˚05'46. 00" to 00° 05' 08.13" S and longitudes 34˚ 41'15. 96" to 34° 45' 01.76" E (Kisumu County, Western Kenya) (Figure 1). The area is characterized with commercial and industrial activities that include Kisumu International Airport, Molasses Plant, Kenya Pipeline Depot, Coca-Cola Plant, Kenya Marine and Fisheries Research Institute (KMFRI), Kenya Medical Research Institute (KEMRI), Port Florence Hospital, Kisumu-Busia Highway and Kisumu-Butere Railway Line running parallel to the lakeshore, and Bandani and Obunga slums. These activities dispose of their effluents, either poorly treated or untreated directly or indirectly into the lake [15]. Two rivers traverse the area and drain into the lake. River Kisat, drains through Kisumu Industrial Area while River Kisian flows through an area characterized with minimal anthropogenic activities.

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River Kisat, Coca-Cola Plant, Molasses Plant and River Kisian discharge points were the sampling sites. Samples in triplicates were obtained from three sampling points at intervals of 50 m from the shore into the lake at each discharge site (Kisat-K1, K2 and K3, Cocacola-C1, C2 and C3, Molasses Plant- M1, M2 and M3, Kisian- K4, K5 and K6) (Figure 1) during the wet season (April-June 2013) and dry season (January-March 2014). Surface sediment samples (0-2 cm soil depth) were taken using a pre-cleaned stainless-steel Ekman grab sampler, stored in polythene bags, then transported to laboratory for processing and analysis (Nichole and Mason, 2001). The sediment samples were oven dried at 105°C, crushed to powdered form, then 1.0 g from each replica of the less than 63 µm grain size fraction, were digested for 3 hours at 100°C using 10 ml mixture of concentrated HNO_3 and HCl (4:1, aqua ragia digestion). The digests were cooled, filtered through 0.45 µm polyethersulfoon filter membrane into 50 ml volumetric flasks then were topped up to the mark with de-ionized water (Nichole and Mason, 2001). The Cd, Cr, Cu, Fe, Mn Pb and Zn levels were determined using an atomic absorption spectrophotometer (Shimadzu AAS-6200). The data was subjected to statistical analysis at ($p \leq 0.05$) to determine the analytical significance.

Results and Discussion

The variations in heavy metal levels at different sites, seasons and distances from the shore into the lake are given in Table 1. The levels of the heavy metals in sediments were significantly ($p \leq 0.05$) different from one site to another (Table 1). The highest and lowest heavy metal levels were in sediments from Rivers Kisat and Kisian discharge points respectively. The variations in heavy metal concentrations were due differences in anthropogenic activities in the different sites. River Kisat drains through an area characterized with industrial activities while River Kisian traverses an area with minimal activities characterized with sparsely populated rural settlements and peasant agriculture. The sediments from the lakeshore sites with intense anthropogenic activities had higher heavy metal concentrations than those with fewer activities. Such distribution was in a previous study [16]. The results demonstrate the anthropogenic activities within a site were largely responsible for high heavy metals concentration in the sediments from the lake.

The levels of the heavy metals in the sediments were higher than those of Naples Harbour in Italy. However, the Shale Standard is usually quick method of identifying heavy metal enrichment in sediments from particular environments [17]. Generally, the concentrations of the heavy metals in the sediments were higher than those of Shale Standard [18] (Table 2). Such concentrations were high even along Kisian catchment with low anthropogenic activities. Therefore, geochemical factors are partially responsible for the high concentrations of the heavy metals in the sediments. However, the anthropogenic activities worsened the situation. It is suggested that industrial activities around the Winam Gulf need to have water treatment ponds that can effectively reduce heavy metals contaminants into the lake water.

The concentration of the heavy metals in sediments from all sites decreased ($p \leq 0.05$) as the distance increased into the lake (Table 1). Similar decrease was in the Mwanza Gulf of Lake Victoria, Tanzania [19]. These results indicate that the heavy metals trapped into the sediments were not in equilibrium with the levels in lake water and there was a dilution effects into the lake. For industrial or domestic uses, it may therefore be safe to source water far away into the lake.

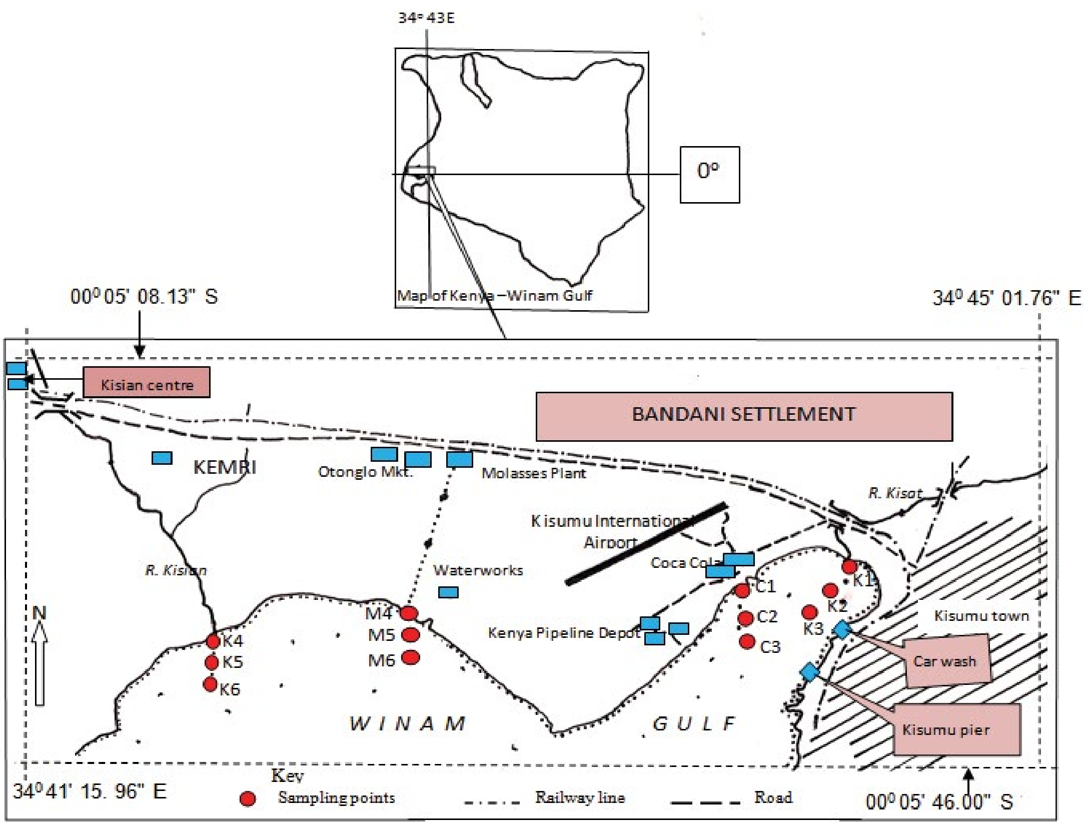

Figure 1: Map of study area showing sampling sites.

Site	Distance	Pb	Cr	Cu	Zn	Fe	Mn	Cd
River Kisat	0 m	198.70	3.60	145.95	209.2	1490.7	1803	1.3
	50 m	188.10	3.55	131.35	178.75	1466.9	1631.45	1.15
	100 m	156.20	3.55	91.35	174.70	1448.25	1609.2	1.10
Mean Distance		181.00	3.60	122.85	187.55	1468.65	1631.20	1.05
C.V. (%)		4.57	0.61	10.09	2.22	0.49	1.11	2.41
LSD ($p \leq 0.05$)		20.54	0.61	30.80	10.35	17.95	44.80	0.06
Mean (season)	Wet	183.25	3.60	129.15	298.45	1520.05	1671.50	1.70
	Dry	178.75	3.55	116.60	76.65	1417.20	1590.95	0.65
LSD ($p \leq 0.05$)		NS	NS	NS	0.50	43.3	36.55	0.18
Coca-Cola Plant	0 m	166.85	3.60	313.85	185.90	1462.75	944.20	1.10
	50 m	155.40	3.50	301.00	171.85	1444.45	913.60	1.10
	100 m	105.10	3.45	188.40	169.40	1437.35	883.15	1.05
Mean Distance		142.45	3.50	267.78	175.70	1448.20	913.65	1.05
C.V. (%)		17.53	0.79	4.99	1.48	0.79	5.92	2.17
LSD ($p \leq 0.05$)		NS	0.06	33.23	6.45	NS	NS	NS
Mean (season)	Wet	152.80	3.55	275.40	281.20	1495.05	997.95	1.55
	Dry	132.10	3.50	260.15	70.20	1401.35	829.30	0.60
LSD ($p \leq 0.05$)		NS	NS	NS	15.55	68.65	NS	0.18
Molasses Plant	0 m	154.15	3.55	134.8	179	1371.95	864.35	1
	50 m	134.00	3.50	117.55	172.9	1314.85	746.7	1.15
	100 m	135.40	3.50	103.45	163.8	1254.1	679	1.1
Mean Distance		141.20	3.50	118.60	171.90	1313.65	763.35	1.05
C.V. (%)		13.40	1.13	21.11	3.81	9.78	1.93	22.33
LSD ($p \leq 0.05$)		NS	NS	NS	NS	NS	36.55	NS
Mean (season)	Wet	143.90	3.55	120.90	275.60	1375.80	793.00	1.50
	Dry	138.50	3.5	116.30	68.20	1251.50	733.65	0.65
LSD ($p \leq 0.05$)		NS	NS	NS	0.785	NS	NS	NS
River Kisian	0 m	67.40	2.65	76.65	102.55	1292	806.7	1
	50 m	60.90	2.50	70.80	99.2	1281.7	786.45	0.9
	100 m	56.95	2.50	66.60	97.35	1276.35	783.6	0.85
Mean Distance		61.75	2.55	71.35	100.10	1283.3	792.25	0.90
C.V. (%)		2.32	1.18	3.91	1.65	0.52	1.09	2.03
LSD ($p \leq 0.05$)		3.56	0.06	6.95	4.10	NS	21.35	0.03
Mean (season)	Wet	63.30	2.60	79.45	128.75	1301.05	809.55	1.20
	Dry	60.20	2.50	63.25	70.65	1265.60	774.95	0.60
LSD ($p \leq 0.05$)		NS	NS	NS	9.90	NS	NS	0.09
Overall mean (season) for all 4 sites	Dry	135.80	3.30	138.15	246.20	1423.00	1068.00	1.50
	Wet	127.40	3.25	134.30	71.45	1333.90	982.25	0.60
C.V.%		12.33	0.93	10.71	2.63	4.69	2.90	11.45
LSD ($p \leq 0.05$)		NS	NS	NS	12.60	NS	85.15	0.36
Overall mean (distance) for all 4 sites	0 m	146.80	3.35	167.80	169.15	1404.35	1067.05	1.10
	50 m	134.60	3.25	155.20	156.00	1377.00	1019.55	105
	100 m	113.40	3.25	112.45	151.30	1354.00	988.75	1.00
C.V%		12.33	0.93	10.71	2.63	4.69	2.90	11.45
LSD ($p \leq 0.05$)		20.14	0.03	19.32	5.25	NS	36.95	1.50
Overall mean (site) for all 4 sites	Kisat	181.00	3.60	122.85	187.55	1468.65	1631.20	1.20
	Coca-Cola	142.85	3.50	267.78	175.7	1448.20	913.65	1.05
	Molasses	141.20	3.50	118.6	171.9	1313.65	763.35	1.05
	Kisian	61.75	2.55	71.35	100.1	1283.35	792.25	0.90
C.V. %		12.33	0.93	10.71	2.63	4.69	2.90	11.45
LSD ($p \leq 0.05$)		17.21	0.023	16.49	4.45	68.55	31.55	0.14
Interactions ($p \leq 0.05$)		SxD=22.91	SxD=0.05 SxS$_1$=0.05	SxD= 21.98	SxS$_1$=6.30 SxD=5.95 DxS$_1$=7.40 SxS$_1$xD=8.40		SxD=42.05 SxS$_1$= 44.65	SxS$_1$=0.18 SxDxS$_1$=2.40

NS=Not significant, S=Site, S$_1$=Season, D=Distance

Table 1: Heavy metal variations in sediments from different sites with seasons and specific distances into the lake from the shoreline.

The levels of the heavy metals in sediments from River Kisat, Coca-Cola Plant and Molasses Plant discharge points were high. But these concentrations were comparable with those recorded near urban centres in previous studies at Winam Gulf in Kenya [20], Mwanza Gulf of Lake Victoria [20,21] in Tanzania (Table 2). They were also in same range as those recorded from Lake Manzala in Egypt although Fe levels were ten-fold lower (Table 2). The results indicate a slow build up of heavy metals in the Winam Gulf sediments. This suggests that there is a continuous need to monitor and control the anthropogenic activities around the gulf. Indeed, the most sustainable way of controlling heavy metal contamination of the Winam Gulf water pollution is to build water treatments ponds that shall reduce the amount of polluted water entering into the lake water.

The area surrounding River Kisat and Coca-Cola Plant discharge points had more industrial activities that discharged wastewater loaded with heavy metals into the lake. As a result, the sediments from the sites had higher heavy metals concentrations. The Fe, Zn, Cr, Cd, Cu and Pb concentrations in sediments at from Molasses Plant discharge point did not vary with the increased distance from the shore into the lake. This implied the Plant is not a significant contributor of heavy metals into the lake. However, the heavy metals levels were higher than levels obtained in previous studies on Lake Victoria sediments (Table 2). There is therefore a continuous increase of heavy metals in the environment surrounding the Molasses Plant. Activities including motorized boating and sand harvesting and surface run offs following rainstorms go on in the discharge point of Molasses Plant along the lakeshore which could be responsible for the rise. River Kisian drains through an area characterized with minimal anthropogenic activities.

As a result the heavy metal levels in sediments from the Kisian discharge point were lower than results obtained in previous studies on sediments from Winam Gulf and Lake Manzala in Egypt, respectively. These results demonstrated that the levels of heavy metals at any discharge point were a reflection of anthropogenic activities in the surrounding environment. It is necessary that means of controlling discharge of heavy metals into the lake waters take into account the anthropogenic activities around the entry points.

There were seasonal variations in the heavy metals concentrations at all sites (Table 1). Wet season recorded higher levels of heavy metals than dry season with an exception of Zn, Mn and Cd, which were significant (Table 1). Surface run-offs following rainfall therefore seem to be the main method of washing the heavy metals into the Winam Gulf lake water. There were significant interactions ($p \leq 0.05$) effects between site and distance in the concentrations of all studied metals in sediments from all the sites (Table 1). The various activities in the different sites contribute the heavy metals into the lake sediments in different patterns. Sediments from areas with dense anthropogenic activities showed higher heavy metal levels than areas with fewer activities. This observation was in line with the assertion that aquatic sediments from areas near urban centres were characterized with high metal levels [18]. Thus, the trend of change of concentrations of studied metals in sediments due to the various sites' activities was not uniform. Significant interactions ($p \leq 0.05$) effects were observed for Fe, Zn, Mn and Cd metals between site and season for all sites (Table 1). The data was in agreement with results from a previous study in Winam Gulf. The heavy metal pollution due to the different anthropogenic activities varied with seasons. However, the patterns of Pb, Cr and Cu levels did not vary with seasons at all sites. The factors contributing to their levels were independent of seasonal anthropogenic activities.

Therefore, the study demonstrated that the heavy metal pollution in sediments from the study area were generally locational and seasonal dependant. There is continued rise in the levels compared to previous studies. The wastewater discharges from the anthropogenic activities within Kisumu city should be treated to reduce/remove heavy metal pollutants before draining into the aquatic ecosystems. Activities within the lake shoreline such as sand harvesting, motorized boating and fishing should be discouraged/minimized.

Study	Cd	Pb	Zn	Cr	Fe	Cu	Mn
Winam Gulf (µg/g) [16]	0.55-1.02	6.02-69.40	2.54-265.00	--	1.18-52.90 (x10³)	0.96-78.60	53.10-616.00
(Tanzania) (µg/g) [6]	7.00	54.60	8.30	12.90	--	26.10	--
Kisumu Port (µg/g) [20]	0.40- 2.80	16.80- 76.80	--	--	--	--	--
Lake Victoria, Tanzania (µg/g) [5]	0.16- 0.55	4.80- 65.60	9.00-137.00	1.60 - 0.55	0.01- 0.28	1.70-26.10	--
Lake Victoria (µg/g) [14]	0.26-2.40	8.10-152.20	37.70-441.60	--	960.00-70619.30	185.00-93.10	--
Lake Victoria, Kenya (µg\g) [7]	1.91	138.00	443.00	--	73200.00	100.00	--
Lake Avsar, Turkey (µg\g) [18]	--	0.64-6.35	--	9.41-19.90	19680.00-28560.00	18.20-38.40	--
Winam Gulf, Kisat area (µg\g) [10]	0.00	0.51	2.25	0.18	--	--	--
Lake Manzala, Egypt (µg\g) [19]	33.00-110.00	78.00-174.00	202.00-576.00	--	20018.00-56212.00	106.00-412.00	--
Background Levels (µg\g) [1]	0.20 ± 0.10	23.00 ± 3.70	56.00 ± 25.00	21.60 ± 6.90	--	21.00 ± 6.40	479.00 ± 64.00
Shale standards. (µg\g) [4]	0.30	20.00	95.00	--	--	45.00	--
Current study (µg\g) Kisat	1.20	181.00	187.55	3.60	1468.65	122.85	1631.20
Coca-Cola	1.05	142.85	175.7	3.50	1448.2	267.78	913.65
Molasses	1.05	141.20	171.9	3.50	1313.65	118.6	763.35
Kisian	0.90	61.75	100.1	2.55	1283.35	71.35	792.25

Table 2: Comparison of heavy metal levels (µg/g) in sediments with data from related studies in Lake Victoria and other lakes in other regions, background, and Shale standard concentrations.

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