An Assessment of Heavy Metal Pollution in Sediments of a Tropical Lagoon: A Case Study of the Benya Lagoon, Komenda Edina Eguafo Abrem Municipality (KEEA) — Ghana

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Background. Elevated concentrations of heavy metals in soil have detrimental consequences on the environment, which translates into damaging effects on humans.
Objective. An evaluation was carried out to determine the concentrations of seven heavy metals (As, Cd, Cr, Cu, Hg, Pb, Zn) in soil sediments collected from 12 different stations within the Benya Lagoon in Komenda Edina Eguafo Abrem Municipality (KEEA) in Ghana.
Methods. The calibration and concentration measurements of the elements were carried out using a fast sequential hydride generation atomic absorption spectrophotometer.
Results. An assessment according to metal concentration in terms of abundance found that Pb registered the highest, while a comparison with standard sediment criteria by USEPA and CBSQG indicated heavy pollution levels of As, Cd, Hg, and Pb. Using Pearson's coefficient matrix, As-Cd had a correlation of 1.000, while Zn-Pb registered 0.858, indicating the same or similar source input for each pair. Both the geo-accumulation index (I_{geo}) and the contamination factor (C_F) gave the extent of contamination in the order Cd > Pb > As > Hg > Cu > Cr > Zn, while the degree of contamination C_d at the stations was in the order 1 > 3 > 4 > 5 > 6 > 2 > 7 > 8 > 9 > 10 > 12 > 11, indicating Station 1 as the most polluted. The Hakanson index established the order of decreasing threat of a potential ecological risk as Cd > Hg > As > Pb > Cu > Cr > Zn.
Discussion. The high sums of the individual potential risks values obtained at the sampling stations point to a possible detrimental effect on the health of inhabitants that use resources directly from the lagoon without treatment, and therefore the need for education to curtail any unanticipated disasters.
Competing Interests. The authors declare no competing financial interests.
Keywords. Benya Lagoon; heavy metal pollution; Pearson's coefficient matrix correlation; geo-accumulation index; degree of contamination; Hakanson index/potential ecological risk assessment
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Introduction

High concentrations of heavy metals in soils are a grave health concern as they have adverse effects on the environment and all living things therein. Such health risks occur as living organisms, including humans, breathe in dust coming from soils laden with heavy metals or eat plants tainted with them. The plants may be contaminated through normal uptake when cultivated on affected soils or when irrigated with polluted water. For this study, the heavy metals investigated were arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn).

The Benya Lagoon is located along the Gulf of Guinea within the Komenda Edina Eguafo Abrem (KEEA) municipality, in the Central Region of Ghana (*Figure 1*). This lagoon has been reported by the Environmental Protection Agency (EPA) to be one of the most polluted lagoons in the country and is drying up as a result of its heavy pollution. This development threatens the livelihood of the fishermen living in the KEEA municipality. The seriousness of this pollution has long been identified, but so far no actions have been taken to rectify and reverse this trend.[1] Despite the EPA's report on the heavy pollution in the lagoon, commercial activities around it, which include fishing and mining of salt, still thrive and are on the increase.

The lagoon is principally fed from the Gulf of Guinea and then runs through the community in various directions, as depicted in Figure 1. The water on its northern side is pumped into constructed ponds around the lagoon where salt is mined. The fish and salt obtained from the lagoon are highly utilised as traders from within and outside the KEEA District come to purchase either for consumption, sale in other markets in the country, or export to other West African countries.[2]

Sanitation in the KEEA municipality is poor, resulting in serious environmental problems. Treatment and disposal facilities for solid and liquid wastes are not available, resulting in wastes being directly poured into the lagoon without any form of treatment. Additionally, most of the houses within the vicinity do not have appropriate sanitation facilities, resulting in human excreta being directly dumped into open spaces and drains and eventually ending up in the lagoon. Such practices have often led to the outbreak of diseases like cholera, yaws, dysentery and malaria. Residents also resort to the open burning of refuse which makes way for others to continuously dump waste, resulting in atmospheric pollution.[2] During heavy rainfall, high runoffs are generated within the municipality due to the lack of good drainage systems. This causes flooding, with debris eventually being swept into the lagoon.

The lagoon is also polluted as a result of the open defecation and littering activities of pigs, goats and other domestic animals roaming within the municipalities. The residual fertilizers and pesticide from farms, solid wastes such as metal-scraps, lead and iron filings from local auto-mechanic shops located along the banks of the lagoon, liquid wastes from domestic activities, fuel stations and commercial food vendors are also sources of pollution in the lagoon (*Figure 2–5*).[2]

Heavy metal contamination in an aquatic environment is of critical concern due to its toxicity and adverse bio-accumulation effects on the habitat. Exposure to heavy metals has been linked to several human diseases such as developmental retardation, especially in children, malformation and kidney damage, cancer, abortion/miscarriage, and has an effect on intelligence level and behaviour, and may even cause death in cases of extreme exposure.[3,4,5]

The aim of this study is to assess the level of heavy metal contamination

Abbreviations

AAS	atomic absorption spectrophotometer	*GAEC*	Ghana Atomic Energy Commission
As	arsenic	*HCI*	hydrochloric acid
B_n	standard geochemical background value	*Hg*	mercury
C	Celsius	I_{geo}	geo-accumulation index
CBSQG	consensus–based sediment quality guidelines	*KEEA*	Komenda Edina Eguafo Abrem Municipality
C_d	degree of contamination	*kg*	kilograms
Cd	cadmium	*mL*	millilitre
C_F	contamination factor	*mg*	milligram
C^i_D	reference records	$NaBH_4$	sodium borohydride
C^i_F	contamination factor for the i-th element	*Pb*	lead
cm	centimetre	*PER*	Potential Ecological Risk
C^i_R	measured concentration values in sediments	*RI*	individual potential risk
Cr	chromium	*SD*	standard deviation
Cu	copper	*SQG*	Sediment Quality Guidelines
E^i_r	Potential Ecological Risk	T^i_r	metal toxic response factor for a given substance
EPA	Ghana Environmental Protection Agency	*USEPA*	United States Environmental Protection Agency
g	gram	*Zn*	zinc

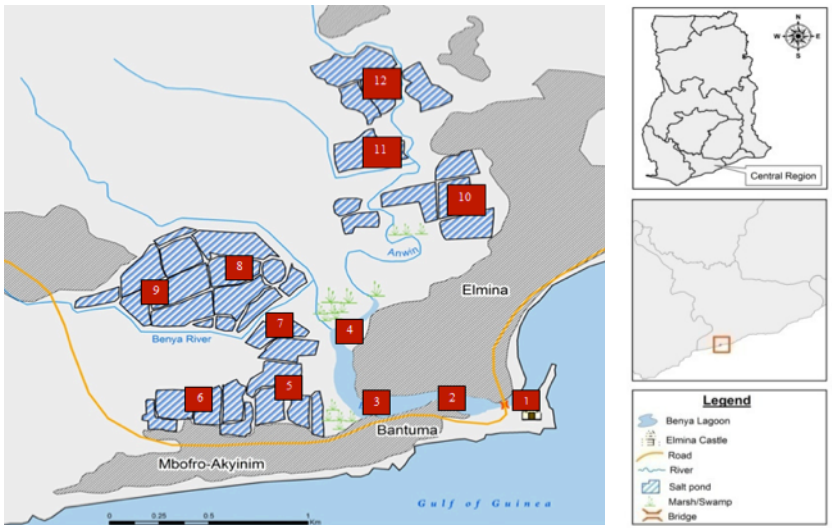

Figure 1 — Map of Benya Lagoon.[6]

in soil sediments collected from 12 different stations in the Benya Lagoon in KEEA, Ghana. The pollution status in these areas is highlighted, while the relationships between metal pollutants are also presented.

Methods

Study Area/Sampling Stations

Twelve fixed-sampling stations 1-12 (marked red on map, *Figure 1*) with a distance of about 100 m to 300 m between them were selected and marked along the Benya Lagoon for the present study. Due to the size of the lagoon and distance between the salt ponds, a non-probability sampling technique, known as convenience

Figure 2 — Waste around the lagoon. Human settlement in the background.

Figure 3 — Liquid and solid wastes dumped near boats.

Figure 4 — Market and repair shops at the background.

Figure 5 — Dumping ground for unused fishing items.

sampling, was employed in the selection of the sample spots. The spots numbered on the lagoon map are the stations where the samples were collected for analysis and are relatively easily accessible places on the lagoon.

Sampling and Sample Collection

All sampling equipment and new containers were pre-cleaned with heavy metal grade acetone before and after use. Heavy metal grade hydrochloric acid (HCl) was also used to rinse all containers before placing the samples in them. For quality control, blank determinations were carried out.

The services of professional fishermen were employed during the sampling period as their boats and skills aided in reaching some of the not easily accessible stations earmarked for investigation.

Superficial (upper 10 cm) sediment samples were randomly collected using a sediment coring device at a speed of not more than 0.3 m/s near the banks of the lagoon at all of the sampling stations. The upper and middle 5 cm of sediment samples were removed with a pre-cleaned spoon and placed in a sampling bowl. The process was repeated for three (3) different areas within each sample station and placed in the same bowl to form a composite sample. The composite sediment samples were then mixed until a uniform colour and consistency was achieved. This was repeated at every sample station, yielding a total of 12 composite samples. The composite sediment sample from each station was then placed in a plastic container, coded with indelible pen, and placed in a labelled Ziploc bag to avoid cross contamination. They were then stored in a refrigerator and transported to the Ghana Atomic Energy Commission (GAEC) Preparation Laboratory for digestion and analyses.

Heavy Metal Composition

Calibration and concentration measurements of elements in the samples were carried out using a PC–based Varian AA240 fast sequential hydride generation atomic absorption spectrophotometer (AAS). AAS was the preferred choice due to its simplicity in sample preparation and handling, high sensitivity, detection limit, degree of accuracy and reproducibility and its general advantage over flame photometry and colorimetry methods.[7] Each prepared solution was taken to the AAS instrument for readings with standards from Fluka Analytical (Sigma –Aldrich Chemie GmbH, Switzerland), to serve as internal positive controls. Working standard solutions of Cd, Cr, Cu, Pb, and Zn were prepared from the stock standard solutions.

About 1.0 g of the soil sample was weighed and quantitatively transferred into a 10 mL test-tube. It was wet ashed with 3 mL aqua regia and placed on a hot plate (95^{o}C) to heat for an hour or until all brown fumes ceased. The solution was cooled, filtered and topped to the 10 mL mark with deionised water. It was then sent for hydride generation AAS analysis.

The calibration curves were prepared for each element individually by applying a linear correlation least square method. A blank reading was taken and the necessary correction made during the determination of the concentrations of the various elements.

The quantitative analysis involved the calculation of the final concentrations from the identified elements' initial concentrations and converting them into the final concentrations using Equation 1.

Nominal volume was given as 20 ml and the sample weight for soil was 1.5 grams.

Determination of Hg using cold-vapor AAS and As were also measured using Varian AA 240 fast sequential hydride generation AAS.[8] The instrument was set up according to the manufacturer's specifications. It was equipped with argon to drive the hydride system. HCl (6 M) and sodium borohydride ($NaBH_4$) (0.6%) generated the hydride.

Results

A. Assessment According to Heavy Metal Concentrations

The concentration of each metal investigated in the composite sediment from each sampling station is shown in Table 2. Metal concentrations ranged within the following intervals: As: 14.4-105.6 mg/kg; Cd: 3.6-26.4 mg/kg; Cr: 30.8-100.8 mg/kg; Cu: 4.8-217.6 mg/kg; Hg: 0.4-8.8 mg/kg; Pb: 40.8-309.2 mg/kg; and Zn: 2.0-177.2 mg/kg, and their mean concentrations were: As: 61.9 mg/kg; Cd: 15.5 mg/kg; Cr: 62.6 mg/kg; Cu: 56.2 mg/kg; Hg: 1.3 mg/kg; Pb: 109.4 mg/kg; and Zn: 45.4 mg/kg. Arranging the metals in terms of abundance in the sampling sites yielded the order Pb > Cr > As > Cu > Zn > Cd > Hg. The high standard deviation (SD) values obtained indicate that the spatial distribution of the individual metal contamination at the various sampling sites was not uniform.

$$\text{Final Concentration} = \frac{\text{Initial Concentration x Normal Value}}{\text{Sample Weight in Grams}}$$

Equation 1

Stations	As	Cd	Cr	Cu	Hg	Pb	Zn
1	105.6	26.4	36.4	11.6	8.8	48.8	18.4
2	60.8	15.2	30.8	217.6	0.8	74.4	3.6
3	99.2	24.8	85.2	4.8	1.2	309.2	101.2
4	96.0	24.0	58.4	80.8	0.4	56.8	2.0
5	89.6	22.4	59.6	24.4	0.4	54.8	50.4
6	64.0	16.0	78.0	74.0	0.4	292.4	177.2
7	49.6	12.4	100.8	44.8	1.6	110.4	36.4
8	49.6	12.4	82.0	21.2	0.4	67.6	22.4
9	43.2	10.8	92.0	32.8	0.4	110.8	40.0
10	41.6	10.4	41.2	106.4	0.4	58.4	31.6
11	14.4	3.6	44.8	39.2	0.8	40.8	44.0
12	28.8	7.2	42.4	16.8	0.4	88.0	17.2
Min	14.4	3.6	30.8	4.8	0.4	40.8	2.0
Max	105.6	26.4	100.8	217.6	8.8	309.2	177.2
Mean	61.9	15.5	62.6	56.2	1.3	109.4	45.4
SD	29.6	7.4	24.0	59.5	2.4	92.2	49.1
B_n	13.0	0.2	97.0	32.0	0.4	20.0	129.0

Table 2 — Concentration of Heavy Metals (mg/kg) from Each Sampling Station
B_n is the standard geochemical background value.

The high levels of heavy metals registered in the sediments of the Benya Lagoon could possibly be attributed to the following activities that took place in and around the KEEA in the past. From 1482 to 1486, the Portuguese built Elmina Castle on a strategically narrow strip of land bounded by the ocean (Gulf of Guinea) and the Benya River. The river provides a natural shelter harbour and feeds the lagoon with water. The castle was built to protect the gold rich land of 'El Mina' ("the mine"), and the surrounding area well noted for trade activities involving gold.[9] Due to these past activities along the banks of the lagoon, there is a slow transfer through the dynamic equilibrium process of erosion and accretion of heavy metals. In the 1980's, Ghana sold petroleum fuel laced with Pb, and more recently in 2012, activity involving the mining of gold around the lagoon was stopped by the government, although some inhabitants claimed they had discovered gold in the area.

Nets used for fishing have lead ingots attached to their ends to act as weights to help sink the nets to the bottom of the lagoon. These ingots are prepared along the banks of the lagoon. These past and present activities may explain why the lagoon is so heavily contaminated by Pb, As and Hg, with Pb registering the highest concentration of 309.2 mg/kg at sampling site 3.

The presence of Cu and Cd in the lagoon may be attributed to spillages from products such as Cd batteries, detergents, paints, inks used for printing, boating activities, domestic garbage dumps and sewage treatment plants, urban wastewater runoffs and industrial effluents, phosphate fertilizers in agricultural runoff, mining activities, impurities from electroplating steel, and the remixing of petroleum products. Cr is used in the manufacture of cements, pigments for paints, paper, rubber and metal alloys. Some activities around the lagoon make use of cement, paints and paper products, which eventually end up being washed into the lagoon.[10]

The highest metal concentration values for As, Cd and Hg were recorded at Station 1, while Station 2 and 3, respectively, registered the highest concentrations for Cu and Pb. This was to be expected, as the fish market, repair and fabrication shops for lead ingots and fuel dispensing points are all concentrated at these sample stations. Zn and Cr had the highest concentration values registered at Station 6 and 7, respectively, which are residential areas and therefore have homes and settlements around them.

B. Assessment According to the Correlation between the Elements

To determine the correlation, if any, between the heavy metal sediment samples studied, Pearson's correlation coefficient matrix was used and the findings are presented in Table 3. The correlation coefficients between elements give information about their possible sources.[11]

The significant correlation between the contaminants of As and Cd (r = 1.000) and Zn and Pb (r = 0.858) could indicate the same or similar source inputs. Elmina is an old town with very old buildings roofed using zinc sheets with lead paints. Therefore, the high correlation between Zn and Pb in sediment could be attributable to roofing sheets and paints from the homes located along the banks of the lagoon.

Cd is a soft metal which can form complex compounds, usually hydrated, with carbonated, arsenate, phosphate, or oxalate ions. The presence of As-Cd at a location has been attributed to the inappropriate disposal of radioactive waste, soil parent materials, sludge, industrial effluents, fertilizers in agricultural runoff and atmospheric fallouts.[12]

C. Assessment According to the United States Environmental Protection Agency (USEPA) and Consensus–Based Sediment Quality Guidelines (CBSQG) SQG (2003)

The concentrations of metals investigated were compared with sediment criteria proposed by the USEPA and CBSQG.[13,14] The findings are shown in Table 4. The average concentration of As, Cd, Hg, and Pb according to the CBSQG scale indicated a heavy pollution level, with Pb and Cd also registering a heavy pollution level according to the USEPA standard.

The mean concentration of 56.2 mg/kg registered for Cu indicates a 'heavy pollution level' according to the USEPA standard and a 'slight pollution level' according to the CBSQG scale. Cr, according to both the USEPA and CBSQG scale, registered an average of a 'slight pollution level', but some of the sampling stations registered concentration values way above the 'heavily polluted levels' according to both the USEPA and CBSQG standards.

	As	Cd	Cr	Cu	Hg	Pb	Zn
As	1						
Cd	**1.000**	1					
Cr	0.029	0.029	1				
Cu	-0.101	-0.101	-0.422	1			
Hg	0.467	0.467	-0.280	-0.238	1		
Pb	0.246	0.246	0.510	-0.143	-0.161	1	
Zu	0.104	0.104	0.419	-0.181	-0.163	**0.858**	1

Table 3 — Correlation Matrix between Heavy Metals in Sediment Samples

	USEPA Pollution Level (mg/kg)			USEPA Pollution Level (mg/kg)			USEPA Pollution Level (mg/kg)	
Metal	Not	Slightly	Heavily	Not	Slightly	Heavily	Range	Mean
As	----	----	----	< 9.8	9.8 – 21.4	> 21.4	14.4 – 105.6	61.9
Cd	----	----	> 6	< 0.99	0.99 – 3	> 3	3.6 – 26.4	15.5
Cr	< 25	25 – 75	> 75	< 43	43 – 76	> 76	30.8 – 100.8	62.6
Cu	< 25	25 – 50	> 50	< 25	25 – 75	> 75	4.8 – 217.6	56.2
Hg	----	----	----	< 0.18	0.18 – 0.64	> 0.64	0.4 – 8.8	1.3
Pb	< 40	40 – 60	> 60	< 40	40 – 70	> 70	40.8 – 309.2	109.4
Zu	< 90	90 – 200	> 200	< 90	90 – 200	> 200	2.0 – 177.2	45.4

Table 4 — Comparison with USEPA/CBSQG SQG (2003) Guidelines for Sediment

$$I_{geo} = \log_2[C_n/(1.5B_n)]$$

Equation 2

I_{geo} Class	I_{geo} Class	Sediment Quality
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} \leq 2$	Moderately contaminated
3	$2 < I_{geo} \leq 3$	Moderately to heavily contaminated
4	$3 < I_{geo} \leq 4$	Heavily contaminated
5	$4 < I_{geo} \leq 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

Table 5 — Pollution Grades of Geo-Accumulation Index of Metals I_{geo} class (Muller Scale)

D. Assessment According to Geo-accumulation Index (I_{geo})

The degree of pollution in sediments can also be assessed by determining the geo-accumulation index I_{geo}, a criterion able to evaluate the heavy metal pollution in sediments as originally defined by Muller.[15] It is mathematically expressed in Equation 2, where C_n is the concentration of element '*n*' and B_n is the geochemical background value [world surface rock average given by Martin and Meybeck].[16] The factor '*1.5*' is incorporated in the relationship to account for possible variation in background data due to lithogenic effect. See Table 2 for a listing of the geochemical background values (Bn) for each metal tested. The geo-accumulation index scale consists of seven grades (0–6) defining pollution levels ranging from unpolluted to highly polluted, as given in Table 5.[16] Table 6 gives the calculated I_{geo} values for the metals investigated and the class in which they fall.

	As		Cd		Cr		Cu	
Stations	Value	Class	Value	Class	Value	Class	Value	Class
1	2.44	3	6.46	6	-2.00	0	-2.05	0
2	1.64	2	5.66	6	-2.24	0	2.18	3
3	2.35	3	6.37	6	-0.77	0	-3.32	0
4	2.30	3	6.32	6	-1.32	0	0.75	1
5	2.20	3	6.22	6	-1.29	0	-0.98	0
6	1.71	2	5.74	6	-0.90	0	0.62	1
7	1.35	2	5.37	6	-0.53	0	-0.10	0
8	1.35	2	5.37	6	-0.83	0	-1.18	0
9	1.15	2	5.17	6	-0.66	0	-0.55	0
10	1.09	2	5.12	6	-1.82	0	1.15	2
11	-0.44	0	3.58	4	-1.70	0	-0.29	0
12	0.56	1	4.59	6	-1.78	0	-1.51	0
Mean	1.67	2	5.69	6	-1.22	0	0.23	1

Table 6 — I_{geo} Values and Class for the Metals Investigated in Soil Sediments of Benya Lagoon by Sampling Station

It can be deduced from Table 6 that with reference to the Muller scale, none of the stations showed signs of sediment contamination for Cr and Zn. For Pb, the sediments were moderately contaminated ($1 < I_{geo} \leq 2$) for Station 2, 7, 8, 9 and 12, but were heavily contaminated for Station 3 and 6. Sediments in Station 1 were heavily contaminated with Hg, while Station 7 showed signs of moderate contamination. Station 2, 3 and 11 showed no signs of contamination to moderate contamination and the rest of the stations showed no sign of contamination. Stations 10 and 2 were moderately contaminated and moderately to heavily contaminated for Cu, respectively. Stations 6 and 4 ranged from uncontaminated to moderately contaminated for Cu, while the remaining stations indicated no contamination ($I_{geo} \leq 0$). Cd registered the highest I_{geo} values for all of the stations ('extremely contaminated'), except for Station 11, which recorded a sediment quality of 'heavily contaminated'. From Table 6, it can be deduced that 50% of the samples studied fell within the range 'moderately to heavily contaminated', 33.3% were 'moderately contaminated' while the remaining 16.7% were divided into the 'uncontaminated' and 'uncontaminated to moderately contaminated' categories. Using the mean values of I_{geo}, the sediments studied may be said to be contaminated with metals in the order Cd > Pb > As > Hg > Cu > Cr > Zn.

$$C_F = \frac{\text{Measured Concentration}}{\text{Background Concentration}}$$

Equation 3

	Hg		Pb		Zn	
Station	Value	Class	Value	Class	Value	Class
1	3.87	4	0.70	1	-3.39	0
2	0.42	1	1.31	2	-5.75	0
3	1.00	1	3.37	4	-0.94	0
4	-0.58	0	0.92	1	-6.60	0
5	-0.58	0	0.87	1	-1.94	0
6	-0.58	0	3.28	4	-0.13	0
7	1.42	2	1.88	2	-2.41	0
8	-0.58	0	1.17	2	-3.11	0
9	-0.58	0	1.88	2	-2.27	0
10	-0.58	0	0.96	1	-2.61	0
11	0.42	1	0.44	1	-2.14	0
12	-0.58	0	1.55	2	-3.49	0
Mean	1.15	2	1.87	2	-2.09	0

Table 6 (continued) — I_{geo} Values and Class for the Metals Investigated in Soil Sediments of Benya Lagoon by Sampling Station

E_F	Grade	Intensity
$C_F < 1$	I	Low contamination factor
$1 \leq C_F < 3$	II	Moderate contamination factor
$3 \leq C_F < 6$,	III	Considerable contamination factor
$C_F \geq 6$	IV	Very high contamination factor

Table 7 — C_F Ranges and Their Designated Pollution Grade and Intensity[17]

E. Assessment According to Contamination Factor (C_F) and Degree of Contamination (C_d)

Two useful indicators that reflect the extent of environmental contamination are the contamination factor (C_F) and degree of contamination (C_d).

The contamination factor (C_F) is

$$C_d = \Sigma C^i_F$$

Equation 4

employed to evaluate the possible anthropogenic input of metals to observed sediment.[16] Mathematically, it is expressed as given in Equation 3. The background concentration value of the metal is the world surface rock average as given by Martin and Meybeck.

The degree of contamination (C_d) is used to assess the excessive values of monitored elements in soil sediment samples.[16] Mathematically, it is expressed as given in Equation 4.

C^i_F is the contamination factor for the i-th element.

The five C_F ranges, their pollution grades and corresponding intensities are given in Table 7. The C_F and C_d values of the metals studied from all twelve sampling stations are shown in Table 8.

In this study, the highest C_F value was obtained for Cd, which registered a very high contamination factor with low contamination factors being registered for Cr and Zn. On the basis of the mean C_F values, the sediments may be considered to be enriched/polluted by the metals investigated in the following order: Cd > Pb > As > Hg > Cu > Cr > Zn. Considering the cumulative effect of all of the individual metals present at the stations, Station 1 registered the highest degree of contamination, while Station 11 registered the lowest. In increasing order, the following is the increasing order among the stations with respect to the degree of contamination:
1 > 3 > 4 > 5 > 6 > 2 > 7 > 8 > 9 > 10 > 12 > 11.

	Contamination Factor or Enrichment Factor C_F							
Stations	As	Cd	Cr	Cu	Hg	Pb	Zn	Degree of Contamination C_d
1	8.12	132	0.38	0.36	22	2.44	0.14	165.44 (1st)
2	4.68	76	0.32	6.80	2	3.72	0.03	93.54 (6th)
3	7.63	124	0.88	0.15	3	15.50	0.78	151.90 (2nd)
4	7.38	120	0.60	2.53	1	2.84	0.02	134.37 (3rd)
5	6.89	112	0.61	0.76	1	2.74	0.39	124.40 (4th)
6	4.92	80	0.80	2.31	1	14.60	1.37	105.03 (5th)
7	3.82	62	1.04	1.40	4	5.52	0.28	78.06 (7th)
8	3.82	62	0.85	0.66	1	3.38	0.17	71.88 (8th)
9	3.32	54	0.95	1.03	1	5.54	0.31	66.15 (9th)
10	3.2	52	0.42	3.33	1	2.92	0.24	63.12 (10th)
11	1.11	18	0.46	1.23	2	2.04	0.34	25.18 (12th)
12	2.22	36	0.44	0.53	1	4.40	0.13	44.72 (11th)
Mean	4.76	77.3	0.65	1.76	3.3	5.47	0.35	93.59

Table 8 — C_F and C_d Values for Soil Sediments of Benya Lagoon

F. Assessment According to Potential Ecological Risk (PER)

The Hakanson index is a diagnostic tool used to assess the Potential Ecological Risk (PER) for water pollution control purposes and helps determine which water bodies and substances need to be given special attention.[18] The methodology is based on the assumption that the sensitivity of the aquatic system depends on its productivity. The PER assessment system, defined in Dumcius et al., is based on element abundance and several preconditions:
(1) concentration—aggravated metal pollution degree in sediments increases the PER;
(2) species number—the metals in sediment express the additive effect. Multiple metals increase the PER. As, Cr, Cd, Cu, Hg, Pb and Zn are prior considered objects;
(3) toxic response—heavy biological-toxicity metals have more evidence for potential risks and magnitude for abundance correction;
(4) sensitivity—based on the biological production index (BPI); sensitivity differs in different water quality systems.[19, 20]

Mathematically the PER is expressed as in Equation 5 as:

$$E^i_r = T_r^{\,i} \times C^i_F$$

Equation 5

where $T_r^{\,i}$ is the metal toxic response factor for a given substance.[21]

The values for each element investigated are in the order: Zn = 1 < Cr = 2 < Cu = Pb = 5 < As = 10 < Cd = 30 < Hg = 40.

C^i_F is the contamination factor (a ratio between reference records, C^i_D and measured concentration values in sediments, C^i_R).

The potential ecological risk of a given contaminant is defined in Table 9 and 10. The sum of the individual potential risks (RI) is the potential risk for that particular water body.[19] The risk assessment findings are given in Table 11.

Critical Range for *i*-th Heavy Metal	Grade for Ecological Risk Factor
$E^i_r < 40$	Low
$40 \leq E^i_r < 80$	Moderate
$80 \leq E^i_r < 160$	Considerable
$160 \leq E^i_r < 320$	High
$E^i_r \geq 320$	Very high

Table 9 — Indices and Grades of Potential Ecological Risk Factors

RI Class	Critical Range for Heavy Metal	Grade for Ecological Risk Index
A	RI < 110	Low
B	110 ≤ RI < 220	Moderate
C	220 ≤ RI < 440	High
D	RI ≥ 440	Very high

Table 10 — Indices and Grades of the Potential Ecological Risk Index

Mathematically, RI is expressed as given in Equation 6.

The results suggested that Cd and Hg are the two metals in the Benya Lagoon with PER values that need to be carefully monitored. The calculated PER values for Cr, Cu, Pb and Zn suggest that these metals present a low potential ecological risk. On the basis of the mean values of the PER, the sediments have PER values for the investigated metals in the order Cd > Hg > As > Pb > Cu > Cr > Zn.

$$RI = \Sigma E_r^i$$

Equation 6

Discussion

It has been established that elevated concentrations of heavy metals in soils have detrimental consequences on the environment, which translates into damaging effects on both humans and plants. For humans, high-level exposures have been linked to diseases such as a slowdown in mental development, deformity and damage in the kidney, cancer, and death in cases of extreme exposure. Plants are contaminated when farmed on infected soils or irrigated with polluted water, resulting in the produce from such plants being tainted with these metals. There is therefore the need for a thorough assessment of soils suspected to be polluted with heavy metals.

This examination was carried out on sediments from the Benya Lagoon, a lagoon located along the Gulf of Guinea within the Komenda Edina Eguafo Abrem (KEEA) municipality in the Central Region of Ghana which is reported to be drying up as a result of heavy metal pollution. The metals investigated were arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn).

The sediments were assessed according to metal concentrations and their added magnitudes at all of the sites determined that their measured concentrations were in the order Pb > Cr > As > Cu > Zn > Cd > Hg. The spatial distribution of the respective metal contamination at the various sampling sites was not uniform, as reflected in the high standard deviation (SD) values obtained. Pb registered the highest abundance and this could be attributed to the use of fishing nets with lead ingots that act as weights to sink the nets to the bottom of the lagoon. The preparation of the ingots and attachments to the nets are all carried out along the banks of the lagoon. Until quite recently, Ghana dispensed petroleum fuel laced with Pb. Such activities could be the reason for Pb registering the highest abundance among the metals monitored. The detection of Cu and Cd in the lagoon could be attributed to boating activities and spillages from products like Cd batteries, detergents, paints and inks used for printing.

Pearson's coefficient matrix was used to establish the correlation between the metals and their possible sources. As-Cd, which had a correlation of 1.000, and Zn-Pb, which had a correlation of 0.858, could indicate the same or similar source input for each pair. The Zn-Pb source could be

	Potential Ecological Risk Assessment							
Stations	As	Cd	Cr	Cu	Hg	Pb	Zn	RI
1	81.23	3960	0.75	1.81	880.00	12.20	0.14	4936.13
2	46.77	2280	0.64	34.00	80.00	18.60	0.03	2460.04
3	76.31	3720	1.76	0.75	120.00	77.30	0.78	3996.90
4	73.85	3600	1.20	12.63	40.00	14.20	0.02	3741.90
5	68.93	3360	1.23	3.81	40.00	13.70	0.39	3488.06
6	49.23	2400	1.61	11.56	40.00	73.10	1.37	2576.87
7	38.15	1860	2.08	7.00	160.00	27.60	0.28	2095.11
8	38.15	1860	1.69	3.31	40.00	16.90	0.17	1960.22
9	33.23	1620	1.90	5.13	40.00	27.70	0.31	1728.27
10	32.00	1560	0.85	16.63	40.00	14.60	0.24	1664.32
11	11.08	540	0.92	6.13	80.00	10.20	0.34	648.67
12	22.15	1080	0.87	2.63	40.00	22.00	0.13	1167.78
Mean	47.59	2320	1.29	8.78	133.33	27.34	0.35	2538.69
ER Grade	Moderate	Very high	Low	Low	Considerable	Low	Low	All Σ RI = Very high

Table 11 — Potential Ecological Risk Assessment for Soil Sediments of Benya Lagoon

attributed to the use of lead-painted zinc roofing sheets used along the banks of the lagoon.

The metal concentrations obtained were compared with standard sediment criteria recommended by the United States Environmental Protection Agency (USEPA) and consensus–based sediment quality guidelines (CBSQG). Using these guidelines, the average concentrations of As, Cd, Hg, and Pb indicated heavy pollution levels, while Cr, according to both standards, registered a slight pollution level on average, but registered concentration values way above the heavily polluted levels at some individual sampling stations. The degree of pollution in the sediments was assessed by determining the geo-accumulation index I_{geo}, a decisive factor capable of evaluating heavy metal pollution in sediments. The findings indicated that the sediments showed a moderate contamination level for Pb and no contamination for Cr and Zn. Using the mean values of I_{geo}, the sediments studied may be said to be contaminated with the metals in the order Cd > Pb > As > Hg > Cu > Cr > Zn.

The contamination factor (C_F), which is employed to evaluate possible anthropogenic input of metals to observed sediment, and degree of contamination (C_d), used to assess the excessive values of monitored elements in soil sediment samples, were also used as indicators of the extent of environmental contamination. The highest CF value was obtained for Cd, which registered a very high contamination factor, with low contamination factors being registered for Cr and Zn. On the basis of the mean CF values, the sediments may be considered to be polluted by the metals investigated in the order Cd > Pb > As > Hg > Cu > Cr > Zn.

Considering the cumulative effect of all of the individual metals present at the stations, Station 1 registered the highest degree of contamination, while Station 11 registered the lowest. In decreasing order, the degree of contamination among the stations can be expressed as: 1 > 3 > 4 > 5 > 6 > 2 > 7 > 8 > 9 > 10 > 12 > 11.

The Potential Ecological Risk (PER) for the water from which the sediments were harvested was determined using the Hakanson index. The findings indicated that Cd and Hg need to be watched closely as they registered high values, while Zn had the least potential threat of ecological risk. In order of decreasing threat of an ecological threat, the metals investigated can be arranged in the following order: Cd > Hg > As > Pb > Cu > Cr > Zn.

Conclusion

The high sums of the individual potential risk values (RI) obtained at all of the sampling stations suggest a possible detrimental effect on the health of the inhabitants of the communities that use resources directly from the lagoon without treatment. Contamination of the lagoon could increase over time as activities around it are still ongoing. Attention should therefore be drawn to the rapidly degrading nature of the lagoon and the need for constant monitoring and education for the local population about good environmental practices so as to curtail any unanticipated disasters.

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