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Assessment of physicochemical parameters and heavy metals contamination in Korle and Kpeshie Lagoons, Ghana

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Abstract. *Clottey CA, Nukpezah D, Koranteng SS, Darko DA. 2021. Assessment of physicochemical parameters and heavy metals contamination in Korle and Kpeshie Lagoons, Ghana. Indo Pac J Ocean Life 6: 36-50.* Lagoons are highly productive coastal systems that could provide natural services to the surrounding ecosystem; however, their pollutions cause adverse changes in their natural environment. Korle and Kpeshie Lagoons in Ghana receive waste from industries and municipal sewage. Controlling and monitoring contaminants in these systems is very important to environmental protection. This study examined the presence of heavy metals (arsenic, chromium, copper, cadmium, lead, and zinc) in sediments, crabs (*Callinectes amnicola),* and fish *(Sarotherodon melanotheron)* at Kpeshie and Korle Lagoons. Although lagoons are highly productive coastal systems that offer ecosystem services, their pollution has a negative impact on the surrounding environment. Municipal sewage and industrial waste are dumped into Ghana's Korle and Kpeshie Lagoons. Contaminant monitoring and control in these systems are crucial for environmental protection. The study compared the concentrations of the heavy metals (arsenic, cadmium, copper, chromium, lead, and zinc) in sediments, crabs (*C. amnicola*), and fish (*S. melanotheron*) at Kpeshie and Korle Lagoons to the environmental standards set by international organizations like the WHO and US EPA. The sediments from the Korle and Kpeshie Lagoons had traces of contamination in the following metal concentrations in *S. melanotheron*: cadmium, copper, zinc, lead, chromium, and arsenic, in that order: As, 0.397 ± 0.07; Cd, 1.10 ± 1.31; Pb, 1.227 ± 5.77; Cu, 3.494 ± 4.56; Cr, 5.895 ± 9.76; Zn, 23.225 ± 10.93, and in *C. amnicola*: As, 0.288 ± 0.07 $mgkg^{-1}$; Cd, 4.60 ± 2.69 $mgkg^{-1}$; Cr, 39.521 ± 55.89 $mgkg^{-1}$; Cu, 31.085 ± 16.26 $mgkg^{-1}$; Pb, 10.902 ± 12.95 $mgkg^{-1}$; Zn, 36.042 ± 17.8 $mgkg^{-1}$. The sediments are severely polluted with Cd and Pb, according to pollution indices like pollution load index (PLI), contamination factor (Cf), and potential ecological risk index (RI). The FAO/WHO-allowable limit for cadmium, chromium, and lead was exceeded in *C. amnicola* and *S. melanotheron*. Consumption of *C. amnicola* and *S. melanotheron* does not appear to pose a potential non-carcinogenic health risk on an individual's daily basis. The estimated target hazard quotient (THQ) in Kpeshie Lagoon of Cd, Cr, and Pb of the fishery investigated was less than 1.

Keywords: Coastal systems, controlling and monitoring, environmental, pollution

INTRODUCTION

Humans and other living creatures can benefit from waterbodies. They consist of the sea, the ocean, rivers, lakes, and lagoons. The current study focuses on coastal lagoons, which are shallow coastal pools completely or partially isolated from the ocean by either sand bars (Isla 2009) or embankments along the coast. They rank among the world's most productive aquatic ecosystems. Furthermore, they act as nutrient recyclers, toxins filters, habitats for various species, and nursery grounds in their systems to maintain biological activities. Coastal lagoons are created when marine sediments accumulate in low-lying areas and are either open to or closed to the ocean entrance (Woodroffe 2002). Due to persistent heavy metal contamination and other pollutants, such as Poly Aromatic Hydrocarbons (PAH), caused by nearby communities and industrial activities, these coastal lagoons are in danger of disappearing (Bourgoing 1996). According to Sparks (2005) and Mwatsahu et al. (2020), the sediments in coastal lagoons act as sinks for heavy metals. Heavy metals are adsorbed either on or in the suspended particulate matter of the water bodies. Unfortunately, due to anthropogenic environmental degradation, most lagoons are becoming less valuable ecologically and economically.

Heavy Metals (HM) are defined as any metallic or metalloid chemical elements with relatively high densities greater than 5 gcm-3 and are toxic even at low concentrations (Lenntech 2010). HM are a component of the earth's crust. Although some heavy metals are only minimally necessary for normal growth, they are still considered contaminants. These essential minerals include zinc, iron, copper, and manganese. However, such elements are only relevant at specific concentrations; otherwise, at higher concentrations, they become toxicants.

Wastewater and sewage sludge disposal, by-products from metal mining processes, runoff from agricultural fields, and atmospheric input are all ways heavy metals enter the environment. Heavy metals are considered serious environmental pollutants because of their persistence, toxicity, and capacity to enter the food chain (Kadhum et al. 2016). In addition, these metals can bind to organic substances in the body, leading to cell dysfunction by impeding transport procedures through the cell wall. When organisms and humans are exposed to most metals, the kidney, liver, blood pressure, and other organs are damaged, which can eventually result in death. In addition, according to Baird and Cann (2008), many heavy metals can cause cancer in people.

Lagoons Korle and Kpeshie are open and closed, respectively. The two lagoons are some of the most polluted coastal lagoons in the nation, even though they are not Ramsar Sites (Ramsar Sites have designated wetlands for conserving and wise use of wetlands and their resources under the Convention on Wetlands of International Importance, adopted in Ramsar, Iran, in 1971). Before the water finally enters the Gulf of Guinea, all of Accra's major drainage channels empty their contents through Korle. As a result, high volumes of domestic and industrial waste are discharged into the lagoonal systems, which could have supported socio-economic activities for nearby communities in the Metropolis and provided an attractive landscape (Karikari et al. 2009). In addition, the flow rate of Korle Lagoon has decreased due to high levels of siltation (Asumadu-Sarkodie et al. 2015), resulting in significant flooding in the city of Accra during torrential rains.

Being a closed lagoon (Biney 1984), Kpeshie's water level fluctuates based on hydrologic inputs and outputs (Haines 2009). As a result, the lagoon occasionally overflows into the sea through a small inlet to the ocean or when the water level rises above the sand barrier height. As a result of severe contamination, living organisms in these lagoons are essentially extinct (Boadi and Kuitunen 2002).

The main goal of this study is to assess the presence of heavy metals and their concentrations in crab, fish, sediment, and water in the Korle and Kpeshie Lagoons and compare those concentrations to the permissible limit established by international standards like the Sediment Quality Guidelines (SQG) Canadian Council of Ministers of the Environment (CCME), the United States Environmental Protection Agency (US EPA), and the World Health Organization (WHO). In addition, examining the pollution level in these lagoons was another study goal.

The study's specific goals are to (i) Identify the physical factors that affect metal concentration in water, including total dissolved solids, pH, temperature, electrical conductivity, and dissolved oxygen. (ii) Check the pH of sediment cores. (iii) Assess the levels of heavy metals (As, Cr, Cd, Cu, Pb, and Zn) in water, sediment cores, crabs, and fish from the lagoons. (iv) Compare the metal concentrations in these lagoons. (v) Lagoon contamination levels should be assessed. Finally, calculate the heavy metal Target Hazard Quotient (THQ) in fish and crabs.

MATERIALS AND METHODS

Study area

Ghana's Greater Accra Region includes the lagoons at Korle and Kpeshie, where the study was conducted. According to Boadi and Kuitinen (2003), these lagoons are shallow water bodies in low-lying coastal areas. They once featured beautiful dunes, open mangroves, marshes, and scrubs, and they offered a variety of water birds ample and suitable feeding, resting, and nesting grounds.

Its surface area is roughly 0.127 square kilometers, and is situated 7 meters above sea level in the Accra Metropolitan area's southwestern region. The Odaw River and two other significant drainage channels connect to the Korle Lagoon as it flows from the Abokobi, Adjankote Hills, through Ashongman, Atomic Energy. Then, West Legon, Achimota, Alajo, Avenor, and Agbogbloshie before emptying into the lagoon (Biney 1982). The Korle Lagoon (Figure 1), which is located at geographical coordinates of 0° 13' 20.60" W; 5° 31' 47.46"N and 0° 13' 07.72"W; 5° 31' 48.32"N, could support shellfish and fin fish in the mid-twentieth century. A catchment area of 400 square kilometers discharges industrial waste, sewage from the city, and floodwater into the lagoon, a significant basin. According to Mensah (1976), the discharge water picks up silt and debris as it moves into the lagoon, frequently obstructing the main outlet to the sea. The obstruction gradually lowers the flow rate, depriving the lagoon water of oxygen; where the tides assist in making this portion of the lagoon less polluted, the water quality changes toward the sea (Amuzu 1976).

With a surface area of 0.326 square kilometers, the Kpeshie Lagoon is located in the La-Dade Kotopon district of the Greater Accra Region along the main La-Teshie road (Figure 1). During times of flooding in Gulf of Guinea, the lagoon, which is close to the sea, overflows its barriers. Hospitality businesses are located directly southwest of the lagoon, the Whitler Barracks is to the east, and the La community is to the west. There aren't any significant manufacturing facilities in the catchment area, but several auto repair shops and educational facilities are strewn along the lagoonal stretch that discharges their wastewater into the lagoon. In addition, the lagoon's bank serves as a garbage dump and a place for defecation for the locals. The Kpeshie Lagoon is located at coordinates 0°08' 20.90" W; 5° 33' 54.72"N and 0° 08' 40.52"W; 5° 33' 46.37"N.

Climate, geology, and vegetation

Climate

The tropical savanna climate best describes the study areas. An average of 730 mm of precipitation falls in the region twice a year, during the minor, weaker rainy season that starts in early October and the main rainy season that runs from April to late July. However, rainfall is typically not prolonged but rather brief and intense, which leads to flooding, especially in low-lying areas where the drainage channels are blocked (Amoako and Boamah 2014).

The yearly temperature ranges from a mean of 27.6°C in March to a mean of 25.9°C in August, with very little variation. However, the cooler months are typically more humid than, the warmer ones. As a result, the city has a dry, breezy heat during the summer, especially during the windy Harmattan season.

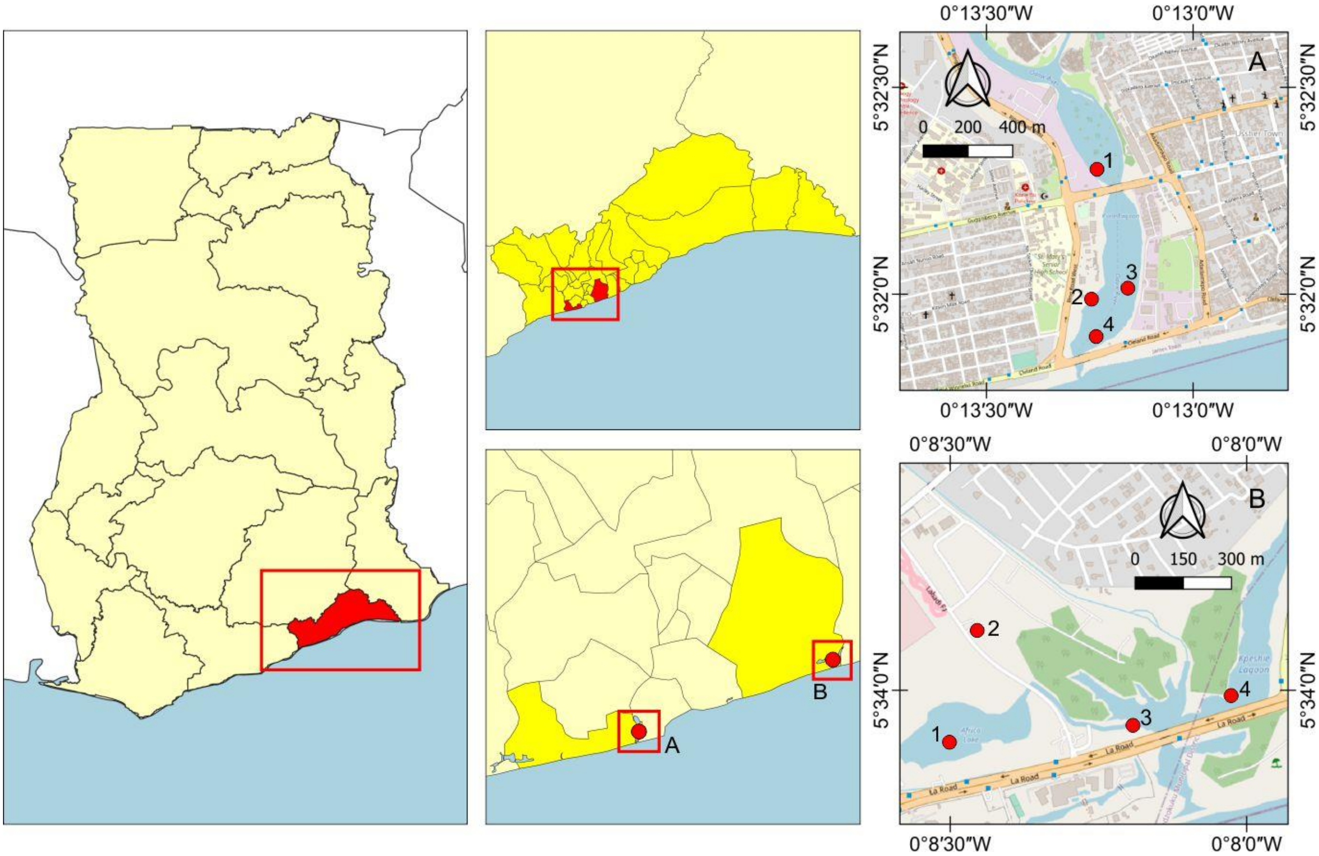


Figure 1. A. Map of Korle Lagoon, with sampling points at Korle Lagoon, Ghana, B. Map of Kpeshie Lagoon, with sampling points at Kpeshie Lagoon, Ghana

Due to their location in a coastal city, the study areas react to climatic changes like a rise in sea level and an increase in temperature, which are brought on by population growth and infrastructure improvements. The threat of silt, debris, and waste materials in drainage channels has serious consequences for public health.

Geology

Sand that receives regular moisture from the ocean makes up the lagoons' coastal shorelines. The Devonian era, which spans 354 to 417 million years, is when the rocks of Korle Lagoon were formed. Sandstone and shale make up most of the rock types of the Sekondian and Accraian units. Depending on the parent rock, the rocks weather into the silt and yellowish-brown clay and are only marginally permeable (Goudie and Viles 2008).

In contrast to the rocks of Korle Lagoon, those of Kpeshie Lagoon are different. The formation was formed between 2 and 1 point 8 million years ago during the Early Proterozoic. These belong to the Dahomeyan unit and are composed of felsic and mafic gneiss, schist, and migmatite rocks (Holm 1973).

Relief and vegetation

The Korle and Kpeshie Lagoons have a coastal savanna relief pattern characterized by low-lying flat land connected to numerous streams and rivers. On average, the lagoons are 7 meters high and gradually empty into the Gulf of Guinea.

The predominant vegetation in the study areas is coastal grassland, which includes scrubs and two different types of grass (Panicum maximum and Imperata cylindrical). In the study areas, many coconut trees are scattered among grassy clumps. In addition, mangrove trees line the lagoon's shores in Kpeshie.

Data collection

Field reconnaissance study

A three-day reconnaissance study was conducted from 20 to 22 October 2017, before data from the study area were collected, to observe the extent of anthropogenic activities like waste disposal, e-waste recovery, and various vehicle repair workshops near the lagoons. During the reconnaissance survey, ideas for the tools and strategy required for sampling were developed.

Sampling

Between November 2017 and April 2018, samples were collected. For example, core sediment samples were taken from four locations in the Korle and Kpeshie Lagoons. The sites were chosen based on activities along the lagoons and vantage points, considering the morphometry. These sample points (Table 1), depicted in Figure 1, were located using the Etrex Global Positioning System (GPS).

A homemade PVC corer measuring 1 meter long and 2 centimeters diameter collected sediment core samples from the lagoons at 30 centimeters depth. Before sampling, the

PVC Corer was cleaned with distilled and lagoon water. Then, the recovered cores were measured by tape, sliced into five cm-long pieces, bagged, and clearly labeled. After being put on ice and transported to the lab, the samples were placed inside a zip-locked plastic bag.

Each sample was homogenously mixed, re-labeled, and stored in polyethylene bags for analysis after being air-dried for 24 and 36 hours (US EPA 2000).

Water sampling

Water samples were taken at each location chosen for sediment core drilling using plastic bottles and distilled water as instructed by the World Health Organization and the United Nations Environment Programme (UNEP/WHO 1996). Before gathering the sample at each sampling location, the bottles were washed with lagoonal water. Nitric acid was added twice to bottles of the sample before being sealed. Water samples were labeled properly, kept on ice, and moved into a refrigerator for laboratory analysis. Using a handheld griffin pH meter, thermometer, dissolved oxygen sensor, electrical conductivity meter, and Total Dissolved Solids (TDS) meter, the following parameters were measured in situ: pH, temperature, Dissolved Oxygen (DO), Electrical Conductivity (EC), and TDS. This strategy was used, specifically for DO, to prevent water changes brought on by the loss of gases or the absorption of gases from the atmosphere (Manahan 2000).

Heavy metal determination in Callinectes amnicola

Fishing in the Kpeshie Lagoon, depicted in Figure 2, led to local fishermen purchasing crabs (Callinectes amnicola). Measurement tape was used to measure the lengths outside, and a weighing scale was used in the lab to record the weight. Atomic Absorption Spectrophotometry (AAS) was used to conduct a total heavy metal analysis on the samples, which were transported to the lab in sealable polyethylene bags with clear labels and kept frozen on ice in an ice chest.

Heavy metal determination in Sarotherodon melanotheron

The fishermen at Kpeshie Lagoon (Figure 3) sold tilapias (*Sarotherodon melanotheron*) on the local market. Next, using a tape measure, the samples' lengths were determined, labeled, and kept in polyethylene bags on ice for storage. Finally, the samples were delivered to the University of Ghana's Ecological Laboratory for examination.

Sample preparations and analysis at the laboratory

Sediment core samples

The lab ground the dried sediment samples with a mortar and pestle and sieved them through a 2 mm mesh. Nitric acid (HNO_3) and perchloric acid ($HClO_4$) were combined in a ternary mixture of 5 mL volume and used to digest one gram (1 g) of sediment in Folin-Wu digestive tubes. In a fume hood, the mixture was heated using a block digester for an hour at 80°C until the solution became colorless. It was then allowed to cool before filtering through Whatman No. 0.45 filter paper. The volume was then adjusted using distilled water. Before measuring the levels of heavy metals in the digested samples, Atomic Absorption Spectrophotometry (AAS) was calibrated using standard solutions of the relevant metals and de-ionized water, and 48 sediment core samples in all were examined. Next, the pH of the sediment was calculated using 10 g of the sediment samples. Then, thirty (30) minutes were spent stirring after adding twenty (20) mL of distilled water. The pH meter was then used to take readings after it had been allowed to sit for 30 minutes.

Water samples

Digestion tubes were filled with 10.5 mL of water samples to calculate the levels of heavy metals. First, add five (5) mL of a ternary mixture (1:1 of concentrated HNO_3 and $HClO_4$). Next, the mixtures were digested for an hour at 80°C, then cooled and filtered into a volumetric flask of 100 ml. Next, to the 100 mL mark, distilled water was added to the solutions. Then, following the procedure outlined by (Bentum et al. 2011), the metal contents were assessed using the Analyst 400 Perkin-Elmer Atomic Absorption Spectrophotometer (AAS). Before measuring the levels of heavy metals in the digested samples, AAS was calibrated using standard solutions of the relevant metals and de-ionized water. There were 24 water samples examined in total.

Table 1. Sampling points locations and descriptions

Points	Lagoon	Longitude	Latitude	Location descriptions
1	Korle	0° 13' 12.864"W	5° 32' 16.836"N	Sewage waste discharge point
2	Korle	0° 13' 08.259"W	5° 32' 04.736"N	Southeastern side
3	Korle	0° 13' 13.565"W	5° 31' 59.412"N	Southwestern side
4	Korle	0° 13' 12.975"W	5° 31' 54.379"N	Close to the estuary
1	Kpeshie	0° 08' 30.501"W	5° 33' 57.124"N	Africa, fishing point
2	Kpeshie	0° 08' 28.781"W	5° 34' 09.742"N	Close to the vehicle garage
3	Kpeshie	0° 08' 10.496"W	5° 33' 58.107"N	Behind the washing bay
4	Kpeshie	0° 07' 56.901"W	5° 34' 02.110"N	Close to the barracks, the fishing point

*Bigfisted swim crab (*Callinectes amnicola*) samples*

The big-fisted swim crab samples (Figure 2) were oven dried at 55°C for 24 hours before being ground to a fine powder in a stainless-steel mill to pass through 1 mm screening. Each powdered sample was weighed at one gram (1g) and digested for an hour in a 5 mL ternary solution of concentrated nitric acid and perchloric acid at a ratio of 1:4. In a 100 mL volumetric flask. The samples were filtered, cooled, and then diluted with distilled water. Before measuring the levels of heavy metals in the digested samples, AAS was calibrated using standard solutions of the relevant metals and de-ionized water. Analyses were performed on twenty-four (24) crab samples.

*Tilapia (*Sarotherodon melanotheron*) samples*

After being cleaned in distilled water, the fish samples (Figure 3) were dried in an oven for 24 hours at 55°C. First, the tissue from dried tilapia was ground into a powder. Then, in digestion tubes inside a fume chamber, one gram (1g) of samples was digested with 5 mL of a ternary mixture of concentrated 1:1 nitric acid and perchloric acid. Afterward, a 100 mL volumetric flask was filled with the sample mixtures. The 100 mL mark was then filled with distilled water. Next, the presence of heavy metals in the filtrates was determined by AAS. Before taking measurements, the AAS was calibrated using standard solutions and de-ionized water, and all 24 samples were examined.

Quality control

Standards and blanks were run before the analysis of the samples to ensure that the instrument was calibrated. The primary methods for examining the contaminations and precisions of the analytes were laboratory blanks and standards. Laboratory glassware was thoroughly cleaned as part of the quality assurance procedures (US EPA 1987).

Data analysis

Data were shown as mean SD in tables. Using SPSS's ANOVA statistical tools, the study's data on heavy metals levels in sediments, water, crabs, and fish were analyzed. The means in each case were compared using a 95% confidence level. Microsoft Excel 10 was used to create all descriptive statistics and graphs.

Contamination factor (Cf)

According to Hákanson (1980), the contamination factor (Cf) is the proportion of a study's metal concentration to the metal's background value in equation 1. This reveals the possibility of sediment contamination.

$$Cf = C_{metal} / C_{background}$$

Where, C_{metal} is the concentration of heavy metal in the sediment; $C_{background}$ is the background metal average concentration level (Taylor 1964) in this study.

Pollution Load Index (PLI)

Sediment environmental quality was evaluated using the pollution load index. The n-th root of the product of the total number of contamination factors (Cf) is used to calculate the pollution load index (Tomlinson et al. 1980), which is defined as follows:

$$PLI = m \sqrt{(Cf_1 \times Cf_2 \times Cf_3 \times \ldots\ldots\ldots \times Cf_m)}$$

Where: m is the number of analyzed heavy metals

Potential Ecological Risk Index (RI)

To calculate the potential ecological risk index (RI) and evaluate the traits and behavior of heavy metal contaminants in environmental samples, particularly sediment, Hákanson (1980) proposed a method (equation 3). The potential ecological risk index (RI) is defined as follows:

$$RI = \sum_{i=1}^{i=m} Er^i$$

Where Er^i is a single potential ecological risk factor, which is defined in equation 4 as the product of contamination factor (Cf) and the toxic response factor for a given heavy metal (Trf^i), and m is the number of analyzed heavy metal

Figure 2. Crustacean samples collected from the field

Figure 3. *Sarotherodon melanotheron* caught in Kpeshie Lagoon, Ghana

$Er^i = Cf \times Trf^I$

Following Hákanson (1980), the standardized toxic response factor (Trf^i)* accepted globally for As, Cr, Cu, Pb, Cd, and Zn are 10, 2, 5, 5, 30, and 1, respectively.

Target Hazard Quotient (THQ)

THQ calculation is to evaluate the non-carcinogenic health effect of heavy metals. THQ formula is defined in equation 5 by (US EPA 2011):

$$THQ = \frac{EFr \times Ed \times FIR \times C}{Rfd \times BWa \times ATn}$$

Where:

EFr is the exposure on the frequency (days per year; 365)

Ed is the exposure duration which is equivalent to the average lifetime (64 years for a Ghanaian adult; WHO 2016)

FIR is the crustaceans' and fish's daily average intake rate (crustacean: 5.42g/person/day; fish: 36g/person/day) (FAO 2005)

C in this study is the mean on heavy metal concentration in fish and crab (in $mgkg^{-1}$)

* Trf^i of a specific metal was derived by Hákanson (1980) from (a) the "abundance principle," (b) the "sink-effect," and (c) the "dimension problem."

Rfd is the trace element oral reference dose (Cd: 0.001mgkg^{-1}/day; Cr: 0.003mgkg^{-1}/day; Pb: 0.004mgkg^{-1}/da) (US EPA 1991)

BWa is the average body weight (considered at 70 Kg for an adult)

ATn is the heavy metal average exposure time (365 days per year x Ed)

RESULTS AND DISCUSSION

Physicochemical parameters of the water

The table below (Table 2) lists the average values of the physicochemical parameters for the study areas.

Korle Lagoon

The pH ranges for the water and sediments of the Korle Lagoon were respectively 4.31- 8.62 and 7.5- 8.4. The mean pH for water was 6.61 ±1.11 and for sediment, 7.81 ±0.28. The lagoon's temperature ranged from 28 to 30°C, with a mean of 29°C. TDS values ranged from 21400 to 36700 mgL^{-1}, while electrical conductivity values ranged from 35200 to 56300 Scm^{-1}. Table 2 shows dissolved oxygen ranged from 0.87 to 3.12 mgL^{-1}, averaging at 1.86 to 0.74 mgL^{-1} (Table 2). Figure 4A shows a scatter plot of electrical conductivity versus TDS for the Korle Lagoons.

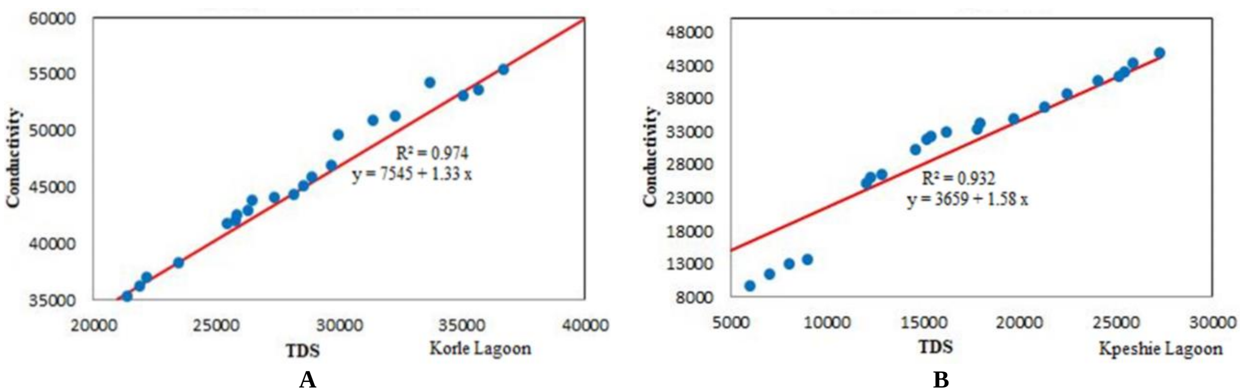
Kpeshie Lagoon

The pH range for water was 3.69-8.48, whereas the pH range for sediments was 7.1- 7.6, with mean values of 7.52-1.22 and 7.36-1.15, respectively. Kpeshie Lagoon's water temperatures ranged from 30.1 to 31.4°C, averaging 30.73 ± 0.41°C. With values ranging from 9600 to 44800 Scm^{-1} and 6050 to 27300 mgL^{-1}, respectively, the electrical conductivity and TDS were both relatively unstable. The scatter plots (Figure 4B) of Kpeshie Lagoon's electrical conductivity versus TDS. Table 2 shows dissolved oxygen values varied from 3.15 to 6.42 mgL^{-1}, averaging 4.58 0.98 mgL^{-1} (Table 2).

Mean heavy metal concentration in water

Heavy metal concentrations in Korle Lagoon water

The mean concentration of arsenic in the Korle Lagoon was 5.410 0.08 ugL^{-1} (all heavy metals in water were analyzed in mgl^{-1} except arsenic in gl^{-1} due to their low concentrations); site 1, the highest level in the water. Site 2, 3, and 4 were 4.968 ± 0.03 ugL^{-1}, 5.400 ± 0.05 ugL^{-1}, and 5.086 ± 0.03 ugL^{-1}, respectively. Site 1 had the highest mean level of cadmium in the water (0.071±0.02 mgL^{-1}), followed by site 2 (0.046 ± 0.01 mgL^{-1}), and site 3 (0.031± 0.02 mgL^{-1}). With a mean of 0.017±0.01 mgL^{-1}, Site 4 had the lowest concentration.



A B

Figure 4. A. A plot of electrical conductivity against TDS of Korle Lagoon, Ghana, B. A plot of electrical conductivity against TDS of Kpeshie Lagoon, Ghana

Table 2. Mean physio-chemical parameters of water and sediments in Korle and Kpeshie Lagoon, Ghana

	Korle Lagoon	Kpeshie Lagoon	WHO 2005	US EPA 2004
PH_water	6.61 ± 1.11	7.52 ± 1.22	6.5-8.5	6-9
PH-sediment	7.81 ± 0.28	7.36 ± 0.15	6.5-8.5	6-9
Temp (°C)	29.41 ± 0.26	30.73 ± 0.41	25-30	25-32
DO (mg/L)	1.86 ± 0.74	4.58 ± 0.98	> 5	> 5
TDS (mg/L)	28390 ± 4633	16516 ± 6430	1000	1000
Conductivity (µS/cm)	45355 ± 6251	29860 ± 10633	1500	1500

The average chromium values on Korle Lagoon were 0.065 ± 0.01 mgL^{-1} at site 1; 0.045 ± 0.02 mgL^{-1} at site 2; 0.037 ± 0.03 mgL^{-1} at site 3, and 0.014 ± 0.01 mgL^{-1} at site 4. The mean values of lead and copper followed a similar trend with cadmium. Site 1 was the highest: 1.216 ± 0.48 mgL^{-1} for Pb; 0.397 ± 0.06 mgL^{-1} for Cu. The lowest value of lead was at site 2 which recorded 0.254 ± 0.14 mgL^{-1}, Followed by copper at site 4, which recorded 0.166 ± 0.05 mgL^{-1}. As indicated in Table 3, the mean concentrations of zinc for sites 1, 2, 3, and 4 were 0.101 ± 0.02 mgL^{-1}, 0.053 ± 0.02 mgL^{-1}, 0.050 ± 0.03 $mgL^{-1,}$ and 0.074 ± 0.01 mgL^{-1}, respectively.

Heavy metals concentration Kpeshie Lagoon water

At site 2, in the Kpeshie Lagoon, the average lowest concentration of arsenic was 4.867 ± 0.05 μgL^{-1}. Site 4 had the highest mean concentration at 5.316 ± 0.27 ugL^{-1}. Site 1 came in second with a mean value of 4.968 ± 0.08 ugL^{-1}, followed by site 3 with a mean value of 5.116 ± 0.02 ugL^{-1}. The lowest mean value for cadmium was recorded at site 1 and was 0.035 ± 0.02 mgL^{-1}. Site 3 came next with 0.037 ± 0.03 mgL^{-1}, followed by site 4 with 0.054 ± 0.01 mgL^{-1}, and site 2 with 0.068 ± 0.01 mgL^{-1}. The mean chromium levels were moderately low, with site 2 having the highest level at 0.073 ± 0.00mgL^{-1} mgL-1. In descending order, sites 3, 1, and 4 measured mean concentrations of 0.073 ± 0.00 mgL-1, 0.060 ± 0.03 mgL^{-1}, and 0.025 ± 0.00 mgL^{-1}.

The values for copper ranged from 0.033-0.566 mgL^{-1}. The average concentration at site 1 was 0.266± 0.15 mgL^{-1} (second highest), 0.241 ± 0.07 mgL^{-1} (second lowest), 0.485 ± 0.21 mgL^{-1} (highest), and 0.038 ± 0.01 mgl^{-1} (lowest). While the lowest mean concentrations of 0.216 ± 0.34 mgL^{-1} at site 3 and the highest of 1.056 ± 0.85mgL^{-} at site 4, lead concentrations ranged from 0.006-2.035 mgL^{-1}. These mean values are shown in Table 3. Zinc concentrations ranged from 0.008 to 0.254 mgL^{-1}. With a value of 0.240 ± 0.01 mgL^{-1}, site 4 recorded the highest zinc concentration.

Heavy mean metal concentration in sediment core

Korle Lagoon sediments

In the lagoon at Korle, arsenic levels were extremely low. The lowest mean was recorded at Site 2 and ranged from 0.4252 to 0.5143 $mgkg^{-1}$. The red line in Figure 5 denotes the SQG limit of arsenic in sediment and shows the low heavy metal concentrations of sediments in the Korle and Kpeshie Lagoons. With values ranging from 0.4825 to 0.5369 $mgkg^{-1}$, site 1 had the highest mean concentration (0.5089 0.02 $mgkg^{-1}$). The concentrations at sites 3 and 4 ranged from 0.3014 to 0.5417 $mgkg^{-1}$ and 0.4359 to 0.5141 $mgkg^{-1}$, respectively. The mean concentrations showed no discernible variations (p-value = 0.85; $p > 0.05$).

Cadmium concentrations in both lagoons are shown in Figure 6, with a recommended limit of 0.7 $mgkg^{-1}$ established by CCME (2001). The levels of cadmium in Korle Lagoon ranged from 1.10 $mgkg^{-1}$ to 54.5 $mgkg^{-1}$. According to Table 4, site 1 measured the highest mean cadmium at 19.067 ± 26.28 $mgkg^{-1}$, while site 3 measured the lowest mean at 5.034 ± 3.92 $mgkg^{-1}$. Sites 2 and 4 had average concentrations of 7.950 ± 1.05 $mgkg^{-1}$ and 6.250 ± 1.75 $mgkg^{-1}$, respectively. The mean concentrations did not vary significantly (p-value = 0.45; $p > 0.05$).

Table 3. Mean heavy metal concentrations of water samples in Korle and Kpeshie Lagoons, Ghana

Lagoon	*As (µg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Standard (WHO)	10.00	0.003	0.05	2.00	0.01	3.00
Korle						
Site 1	5.410± 0.08	0.071 ± 0.02	0.065 ± 0.01	0.397 ± 0.06	1.216 ± 0.48	0.101 ± 0.02
Site 2	4.968 ± 0.03	0.046 ± 0.01	0.045 ± 0.02	0.509 ± 0.23	0.254 ± 0.14	0.053 ± 0.02
Site 3	5.400 ± 0.05	0.031 ± 0.02	0.037 ± 0.03	0.182 ± 0.14	0.478 ± 0.34	0.050± 0.03
Site 4	5.086 ± 0.03	0.017 ± 0.01	0.014 ± 0.01	0.166 ± 0.05	0.482 ± 0.07	0.074 ± 0.01
Kpeshie						
Site 1	4.968 ± 0.08	0.035 ± 0.02	0.060± 0.03	0.266 ± 0.15	0.301 ± 0.04	0.037 ± 0.02
Site 2	4.867 ± 0.05	0.068 ± 0.01	0.075 ± 0.01	0.241 ± 0.07	0.448 ± 0.34	0.027 ± 0.02
Site 3	5.116 ± 0.02	0.037 ± 0.03	0.073 ± 0.00	0.485 ± 0.08	0.216 ± 0.34	0.063 ± 0.04
Site 4	5.316 ± 0.27	0.054 ± 0.01	0.025 ± 0.00	0.038 ± 0.00	1.056 ± 0.85	0.240 ± 0.01

Note: *As (µg/L) was analyzed in microgram per liter due to their low concentrations

Chromium concentrations ranged from 0 $mgkg^{-1}$ to 50 $mgkg^{-1}$. Site 1 had the highest mean, which was observed to be 30.467 ± 16.02 $mgkg^{-1}$, with values ranging from 15.7 to 50.6 $mgkg^{-1}$. Site 2 averaged 14.617 ± 10.47 $mgkg^{-1}$, site 3 averaged 9.933 ± 7.29 $mgkg^{-1}$, and the lowest mean at site 4 was recorded at 6.450 ± 6.11 $mgkg^{-1}$ with values between 0.3 and 14.7 $mgkg^{-1}$ of Cr, as presented in Table 4. These values ranged from 0.5 to 24.5 $mgkg^{-1}$. Figure 7 shows the average chromium concentration in sediments, and the SQG (CCME 2001) limit is shown as a red line. The mean concentrations didn't vary in a statistically significant way (p-value = 0.64; p > 0.05).

Mean copper concentrations were 29.383 ± 37.35 $mgkg^{-1}$ at sites 1, 2, and 3, 11.467 ± 9.02 $mgkg^{-1}$ at site 1, 33.001 ± 0.69 $mgkg^{-1}$ at site 4, and 5.150 ± 4.04 $mgkg^{-1}$ at site 4, respectively. The mean was highest at site 3 and lowest at site 4, respectively. At site 1, their concentrations varied from 4.7 to 78.0 $mgkg^{-1}$, 5.1- 23.5 $mgkg^{-1}$, 32.1-34.1 $mgkg^{-1}$, and from 0.05) in their mean concentrations.

While site 1 recorded the highest mean value of 112.45 48 $mgkg^{-1}$, ranging from 76.8 to 174.6 $mgkg^{-1}$, lead concentrations in sediments at Korle Lagoon sampling sites were higher than other studied metals. Site 2 had the lowest concentrations, measuring an average of 42.917 ±26.23 $mgkg^{-1}$ with values ranging from 25.1 to 78.1 $mgkg^{-1}$, while sites 3 and 4 had higher average concentrations, measuring 59.167 ± 5.92 $mgkg^{-1}$ and 29.700 ± 12.34 $mgkg^{-1}$, respectively, as presented in (Table 4). The concentrations at sites 3 and 4 were between 51.1 and 63.5 mg kg^{-1} and 11 and 41 mg kg^{-1}, respectively. The mean concentrations did not differ significantly (p-value = 0.93; p > 0.05) according to a one-way ANOVA.

Site 3 in Korle Lagoon had consistently higher zinc concentrations than the other sites, averaging 209.001 ± 22.42 $mgkg^{-1}$ and ranging from 189.9 to 241.7 $mgkg^{-1}$. At sites 1 and 2, the mean zinc concentrations were 100.583 93.39 $mgkg^{-1}$ and 126.783 112.54 $mgkg^{-1}$, respectively. Site 1's values ranged from 39.5 to 221.9 $mgkg^{-1}$, while site 2's values ranged from 86 to 205.8 $mgkg^{-1}$. The zinc concentrations at site 4 ranged from 3 to 82 $mgkg^{-1}$, with an average of 13.817 ± 5.85 $mgkg^{-1}$. Site 3 was higher than Site 2 and Site 1 than Site 4, according to the mean zinc concentrations in sediment cores. However, their concentrations had no appreciable differences (p-value = 0.96; p > 0.05).

Kpeshie Lagoon sediment

Similar trends were observed for the arsenic concentrations in sediments at Kpeshie and Korle Lagoons (Figure 5), 0.5063 0.03 $mgkg^{-1}$, 0.5065 0.05 $mgkg^{-1}$, 0.5551 0.03 $mgkg^{-1}$, and 0.4502 0.03 $mgkg^{-1}$, respectively, were the mean values of arsenic at sites 1, 2, and 3. A one-way ANOVA revealed no significant differences in arsenic levels measured at the sampling sites (p-value = 0.79; p > 0.05). The mean values at sites 4 and 2 were the lowest and highest (Table 4).

At the four sampling locations, the cadmium concentrations in the sediments at Kpeshie Lagoon were comparatively similar. The highest mean level for cadmium at 13.867 6.13 $mgkg^{-1}$ was recorded at site 1, with values ranging from 1.7 to 18.1 $mgkg^{-1}$, and site 3 recorded the lowest mean concentration at 5.350 1.51 $mgkg^{-1}$ with values ranging from 3.8 to 7.3 $mgkg^{-1}$. Generally, cadmium concentrations vary with depth and are much higher than the limit set by CCME. According to (Table 4), the mean cadmium levels were 7.550 5.95 $mgkg^{-1}$ at site 2 and 5.750 1.41 $mgkg^{-1}$ at site 4. The single factor ANOVA (p-value = 0.93; p > 0.05) found no significant differences in cadmium levels between sampling sites.

Site 4 recorded the lowest mean of 18.033±13.70 $mgkg^{-1}$, with values ranging from 5.0-37.1 $mgkg^{-1}$. The chromium concentrations in the sediments at the four sampling sites were highly measurable. Site 1 came in second with an average value of chromium of 28.517 ±4.15 $mgkg^{-1}$. Site 3 recorded average chromium levels of 31.400 ±12.36 $mgkg^{-1}$ with concentrations ranging from 18.9 - 45.9 $mgkg^{-1}$, while Site 2 recorded concentrations from 41.5 - 58.7 $mgkg^{-1}$ with the highest mean of 50.833 ± 6.27 $mgkg^{-1}$. Chromium measurements taken at depth (Figure 7) were within the SQG limit of 52.3 $mgkg^{-1}$. At all sampling sites, their mean concentrations did not differ significantly (p-value = 0.99; p > 0.05).

Table 4. Mean heavy metal concentrations in sediment samples in Korle and Kpeshie Lagoon, Ghana

Lagoon	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Standard (CCME)	7.24	0.70	52.30	18.70	30.20	124.00
Korle						
Site 1	0.5089 ± 0.02	19.067 ± 26.28	30.467 ± 16.02	29.383 ± 37.35	112.450 ± 48.00	100.583 ± 93.39
Site 2	0.4728 ± 0.04	7.950 ± 1.05	14.617 ± 10.47	11.467 ± 9.02	42.917 ± 26.23	126.783 ± 112.54
Site 3	0.4956 ± 0.10	5.034 ± 3.92	9.933 ± 7.29	33.001 ± 0.69	59.167 ± 5.92	209.0 1 ± 22.42
Site 4	0.4852 ± 0.03	6.250 ± 1.75	6.450 ± 6.11	5.150 ± 4.04	29.750 ± 12.34	13.817 ± 5.85
Kpeshie						
Site 1	0.5063 ± 0.03	13.667 ± 6.13	28.517 ± 4.15	15.733 ± 16.20	44.333 ± 24.37	114.650 ± 107.22
Site 2	0.5065 ± 0.05	7.550 ± 5.95	31.400 ± 12.36	42.617 ± 2.91	42.283 ± 24.36	69.200 ± 58.28
Site 3	0.5551 ± 0.03	5.350 ± 1.51	50.833 ± 6.27	41.517 ± 40.79	188.433 ±139.77	70.367 ± 10.31
Site 4	0.4502 ± 0.03	5.750 ± 1.41	18.033 ± 13.70	2.408 ± 4.23	56.850 ± 17.05	18.400 ± 4.91

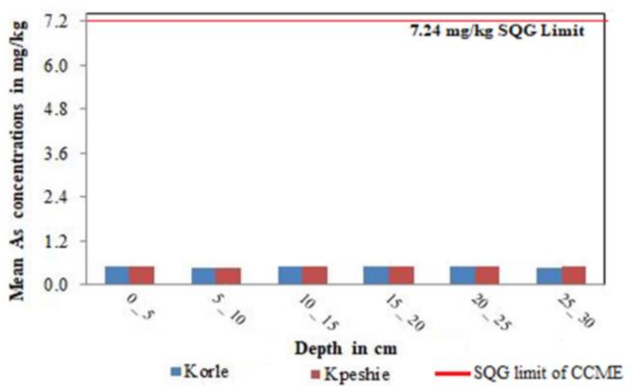


Figure 5. Arsenic concentrations in Korle-Kpeshie Lagoons

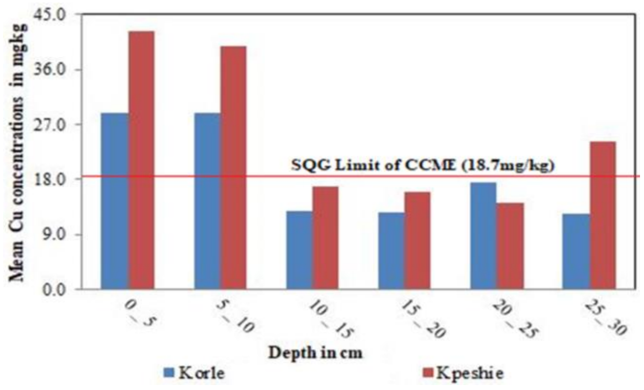


Figure 8. Copper concentrations in Korle-Kpeshie Lagoons

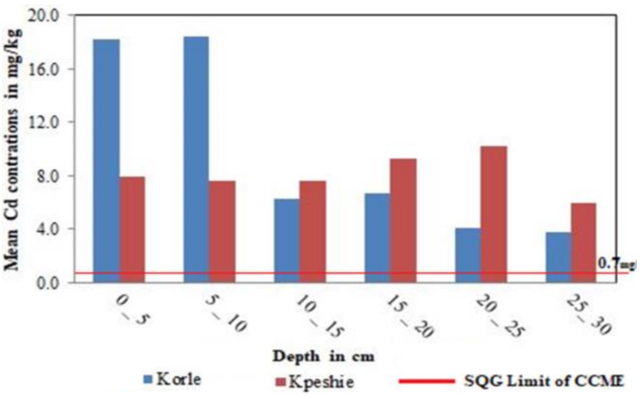


Figure 6. Cadmium concentrations in Korle-Kpeshie Lagoons

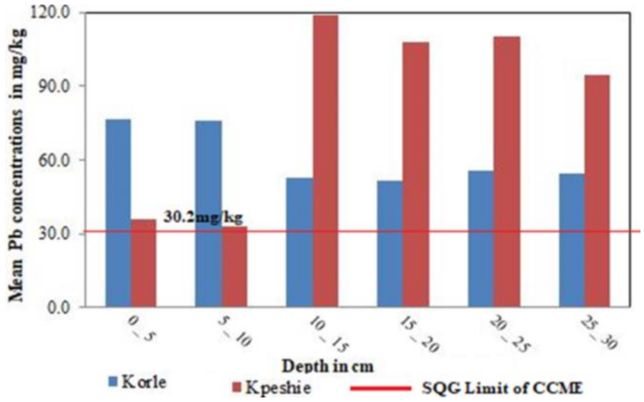


Figure 9. Lead concentrations in Korle-Kpeshie Lagoons

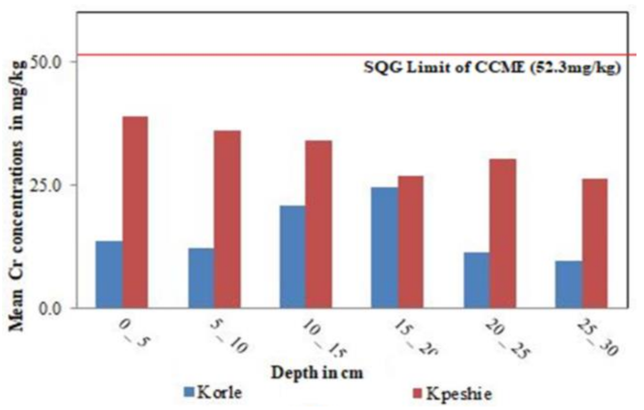


Figure 7. Chromium concentrations in Korle-Kpeshie Lagoons

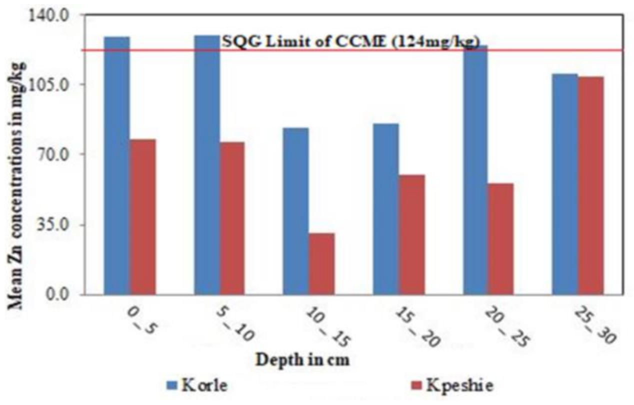


Figure 10. Zinc concentrations in Korle-Kpeshie Lagoons

In general, there was a moderate amount of copper in the sediments of Kpeshie Lagoon. The four sampling sites' copper concentrations yielded individual copper values ranging from <0.001-94.3 $mgkg^{-1}$. The copper levels measured vary considerably with the depth (Figure 8). The average levels were as follows: site 1 (15.733 ± 16.20 $mgkg^{-1}$), site 2, 42.667 ± 2.91 $mgkg^{-1}$, site 3, 41.517 ± 40.79 $mgkg^{-1}$, and site 4, 2.408 ± 4.23 $mgkg^{-1}$, as presented in Table 4.

The four Kpeshie Lagoon sampling locations had moderately high lead concentrations, ranging from 7.9 to 281.1 $mgkg^{-1}$. According to Table 4, the respective mean lead concentrations at sites 1, 2, 3, and 4 were 44.333 ± 24.37 $mgkg^{-1}$, 42.283 ± 24.36 $mgkg^{-1}$, 188.433 ± 139.77 $mgkg^{-1}$, and 56.850 ± 17.05 $mgkg^{-1}$ (Figure 9). Site 2 recorded the lowest mean concentrations, while Site 3 had the highest mean. The mean concentrations at all sampling sites did not differ significantly from one another, according to a single factor ANOVA (p-value = 0.67; $p > 0.05$).

Sites 2 and 3 had moderately low zinc concentrations in the sediments of the Kpeshie Lagoon. The highest mean zinc concentration was found in the sediment at site 1, where zinc levels ranged from 11.7-237.3 $mgkg^{-1}$. Following (Table 4, Figure 10), the average values for sites 2, 3, and 4 were 69.200 ± 58.28 $mgkg^{-1}$, 70.367 ± 10.31 $mgkg^{-1}$, and 18.400 ± 4.91 $mgkg^{-1}$, respectively. The average zinc concentrations at the sampling stations showed no significant differences ($p = 0.73$; $p > 0.05$).

Heavy metal concentration in crab (*Callinectes amnicola*)

The *C. amnicola* were harvested only at Sites 1, and 4 of Kpeshie Lagoon as Sites 2 and 3 could not support living organisms. The mean concentrations of cadmium, chromium, copper, lead, arsenic and zinc in *C. amnicola* of Site 1 were 5.483 ± 2.88 $mgkg^{-1}$, 71.908 ± 64.80 $mgkg^{-1}$; 26.812 ± 19.72 $mgkg^{-1}$; 13.667 ± 17.40 $mgkg^{-1}$; 0.303 ± 0.05 $mgkg^{-1}$; and 45.183 ± 20.70 $mgkg^{-1}$, respectively (Figure 11). The mean concentrations on Site 4 were: arsenic, 0.273 ± 0.08 $mgkg^{-1}$; chromium, 7.133 ± 6.64 $mgkg^{-1}$; copper, 35.358 ± 11.11 $mgkg^{-1}$; cadmium, 3.713 ± 2.26 $mgkg^{-1}$; lead, 8.138 ± 5.61 $mgkg^{-1}$; and zinc, 26.900 ± 7.40 $mgkg^{-1}$, as observed in (Table 5). Except for chromium and zinc, there were no significant differences in the mean concentrations of the sites according to the one-way ANOVA analysis ($p > 0.05$) (Table 5).

Heavy metal concentration in fish (*Sarotherodon melanotheron*)

Sites 1 and 4 at Kpeshie Lagoon were the only locations with fish samples because Sites 2 and 3 were empty. Arsenic and cadmium showed a similar trend in mean concentrations of metals when they were examined in *S. melanotheron* samples from Sites 1 and 4. Fish samples from Sites 1 and 4 had average arsenic levels of 0.3714 0.07 $mgkg^{-1}$ and 0.423 0.07 $mgkg^{-1}$, respectively. Cadmium levels averaged 1.517 1.65 $mgkg^{-1}$ at site 1 and 0.683 0.70 $mgkg^{-1}$ at Site 4. As shown in Table 6, the fish's mean concentrations of chromium, copper, and zinc were (site 1) 2.454 ± 4.58 $mgkg^{-1}$; (site 4) 9.321 ± 12.34 $mgkg^{-1}$, (site 1) 2.929 ± 2.2 $mgkg^{-1}$; (site 4) 4.058 ± 6.15 mgkg-1, and (site 1) 28.642 ± 11.33 $mgkg^{-1}$; (Site 4) 17.81 ± 7.58 $mgkg^{-1}$, respectively. Except for site 4 (28.3 $mgkg^{-1}$), all lead concentrations in *S. melanotheron* were Below the Detection Limit (BDL). Except for zinc, there were no significant differences between the mean concentrations ($p > 0.05$) (Table 6).

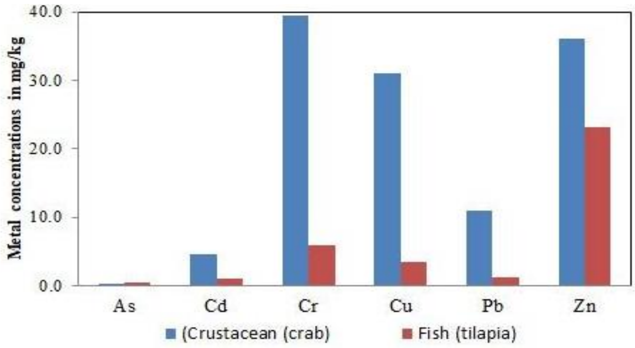


Figure 11. Heavy metal concentrations in crustacean and tilapia

Table 5. Mean heavy metals concentrations in *Callinectes amnicola*

Sampling sites (crustacean) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	US EPA 2010	p-value
As	0.303 ± 0.05	0.273 ± 0.08	0.50	0.29
Cd	5.483 ± 2.88	3.713 ± 2.26	0.50	0.11
Cr	71.908 ± 64.80	7.133 ± 6.64	0.50	0.002
Cu	26.812 ± 19.72	35.358 ± 11.11	70.00	0.20
Pb	13.667 ± 17.40	8.137 ± 5.61	0.50	0.31
Zn	45.183 ± 20.70	26.900 ± 7.40	80.00	0.008

Table 6. Mean heavy metal concentrations in *Sarotherodon melanotheron*

Sampling sites (fish) at Kpeshie Lagoon				
Elements	S1 (mg/kg)	S4 (mg/kg)	FAO/ WHO 2011	p-value
As	0.371 ± 0.07	0.423 ± 0.07	0.26	0.85
Cd	1.517 ± 1.65	0.683 ± 0.70	0.20	0.12
Cr	2.454 ± 4.58	9.321 ± 12.34	0.50	0.08
Cu	2.929 ± 2.20	4.058 ± 6.15	20	0.56
Pb	0.05 ± 0.00	2.404 ± 8.16	1.00	0.32
Zn	28.642 ± 11.33	17.81 ± 7.58	40.00	0.02

Table 7. Correlations between metals in the water column of the lagoons

	As	Cd	Cr	Cu	Pb	Zn
Korle						
As	1					
Cd	0.340	1				
Cr	0.361	0.464	1			
Cu	-0.189	0.525	0.420	1		
Pb	0.589	0.481	0.316	-0.027	1	
Zn	0.306	0.360	0.235	-0.203	0.824	1
Kpeshie						
As	1					
Cd	-0.141	1				
Cr	-0.615	0.215	1			
Cu	-0.301	-0.391	0.473	1		
Pb	0.691	-0.045	-0.578	-0.462	1	

Table 8. Correlations between metals of sediment in the lagoons

	As	Cd	Cr	Cu	Pb	Zn
Korle						
As	1					
Cd	0.061	1				
Cr	0.246	-0.024	1			
Cu	0.075	0.812	-0.167	1		
Pb	0.183	0.789	0.196	0.793	1	
Zn	-0.037	0.379	-0.284	0.795	0.495	1
Kpeshie						
As	1					
Cd	0.217	1				
Cr	0.444	-0.262	1			
Cu	0.305	-0.176	0.316	1		
Pb	0.431	-0.337	0.603	-0.318	1	
Zn	0.281	0.203	-0.070	0.306	-0.190	1

Table 9. Heavy metals relationship in organisms from Kpeshie Lagoon, Ghana

	As	Cd	Cr	Cu	Pb	Zn
Crustacean						
As	1					
Cd	0.316	1				
Cr	0.051	0.074	1			
Cu	-0.023	0.131	-0.762	1		
Pb	0.044	0.260	0.754	-0.598	1	
Zn	-0.092	0.207	0.528	-0.348	0.420	1
Tilapia						
As	1					
Cd	0.125	1				
Cr	0.333	-0.112	1			
Cu	0.353	-0.016	-0.067	1		
Pb	-0.347	0.450	-0.369	-0.184	1	
Zn	-0.562	-0.026	-0.189	0.454	-0.151	1

Correlation studies of the Korle and Kpeshie Lagoons

Using the Pearson Correlation Coefficient, the inter-metal correlation between the heavy metal pairs in Korle and Kpeshie Lagoons found in the water, sediment, crab, and fish was calculated. The results are shown in Tables 7, 8, and 9. Metals in the water column of Korle Lagoon had a few noteworthy positive relationships: Pb-As ($r = 0.589$, $p < 0.05$) and Cu- Cd ($r = 0.525$, $p < 0.05$), while metals in Kpeshie Lagoonal water observed both negative and positive significant correlations between Cr-As ($r = -0.615$, $p < 0.05$), Pb-As ($r = 0.691$, $p < 0.05$), and Pb-Cr ($r = -0.578$).

The Pearson's correlation of sediments in Korle observed a few significant links between Cu-Cd ($r = 0.812$, $p < 0.05$), Pb-Cd ($r = 0.789$, $p < 0.05$), Zn-Cu ($r = 0.795$, $p < 0.05$) and Pb-Cd ($r = 0.793$, $p < 0.05$). On the other hand, sediment in Kpeshie did not observe any significant relationships except Pb-Cr ($r = 0.603$, $p < 0.05$).

The big-fisted swim crab showed positive significant metal correlations between Zn-Cr ($r = 0.528$; $p < 0.05$) and Pb-Cr ($r = 0.754$; $p < 0.05$), and significant trends existed in Pb-Cu ($r = - 0.598$; $p < 0.05$) and Cu-Cr ($r = - 0.762$; $p < 0.05$). Furthermore, the following was discovered by the correlation analysis in tilapia. A significant negative downtrend between Cd-As ($r = - 0.562$, $p < 0.05$), but significant positive correlations existed between Pb-Cu ($r = 0.454$, $p < 0.05$) and Zn-Cd ($r = 0.450$, $p < 0.05$).

Pollution indices of sediments

The degree of heavy metal contamination of the sediment samples from the Korle and Kpeshie Lagoons was determined using pollution indices. The calculated values of the study's sediments' pollution indices are shown in Table 7.

Contamination factor

Table 7 showed that the Cf values ranged from 0.06-97.83. The highest Cf values were found for Cd and Pb, and this trend was seen at all of the sampling locations in the Korle and Kpeshie Lagoons (Table 11). Regarding Cd and Pb, Site 1 at Korle Lagoon had the highest Cf. On the other hand, sites 3 and 4 in the same lagoon had the lowest Cf values for Cd and Pb, respectively.

The Cfs at Kpeshie Lagoon were distinct from those at Korle Lagoon. In Kpeshie Lagoon, cadmium had the highest Cf values. Site 1 had the highest Cd reading of 69 points, while Site 3 had the lowest reading of 26 points. Regarding Cf in Pb, Site 3 recorded the highest value (15.07), while site 2 recorded the lowest value (3.38).

Pollution load index

According to Tables 7 and 10, sediments at Korle Lagoon had a mean Pollution Load Index (PLI) of 1.24, with a range of 0.54 to 1.97. Except for Site 4, which is close to an estuary, all sampling sites had more than one PLI value. Kpeshie Lagoon's PLI values ranged from 0 to 64. A mean score of 1.36 out of 91. Except for site 4, which is close to Whitler Barracks, Sites 1, 2, and 3 all recorded more than one (PLI > 1).

Potential ecological Risk Index (RI)

Potential ecological risk indices of As, Cr, Cd, Cu, Pb, and Zn at all sampling sites were also presented in Tables 7 and 12 based on Hakanason (1980). Compared to Kpeshie Lagoon, where values ranged from 2.58 to 2877.50, sediments in Korle Lagoon recorded values between 1.23 and 5822.50.

Table 10. Average Contamination factor (Cf), Pollution Load Index (PLI), and potential ecological Risk Index (RI) of sediments

Element		n*	As	Cd	Cr	Cu	Pb	Zn	PLI
Korle									
Site 1:	Cf	6	0.28	97.83	0.30	0.53	9.00	1.44	1.97
Site 2:	Cf	6	0.26	39.75	0.15	0.21	3.43	1.81	1.12
Site 3:	Cf	6	0.28	25.25	0.10	0.60	4.73	2.99	1.34
Site 4:	Cf	6	0.27	31.25	0.06	0.09	2.38	0.20	0.54
background values			1.8	0.2	100	55	12.5	70	
	RI		10.90	5822.50	1.23	7.18	97.71	6.43	
Kpeshie									
Site 1	Cf	6	0.28	69.33	0.29	0.29	3.55	1.64	1.45
Site 2	Cf	6	0.28	37.75	0.31	0.78	3.38	0.99	1.43
Site 3	Cf	6	0.31	26.75	0.51	0.75	15.07	1.01	1.91
Site 4	Cf	6	0.25	28.75	0.18	0.04	4.55	0.26	0.64
	RI		11.21	2877.50	2.58	9.30	132.80	3.89	

Note: *n is the number of samples collected at each site; background values were estimated by Taylor (1964)

Table 11. Heavy metals ranking for contamination factor of sediment in lagoons

	Korle	Kpeshie
Cf > 6 high contamination factor	Cd, Pb	Cd, Pb
3 ≤ Cf ≤ 6, considerable factor		
1 ≤ Cf ≤ 3, moderate factor	Zn	Zn
Cf < 1, low contamination factor	As, Cr, Cu	As, Cr, Cu

Table 12. Heavy metals ranking in the potential ecological Risk Index (RI) of sediment

	Korle	Kpeshie
RI > 380, very high ecological risk	Cd, Pb	Cd, Pb
190 ≤ RI ≤ 380, considerable ecological risk		
95 ≤ RI ≤ 190, Moderate ecological risk		
RI < 95, low ecological risk	As, Cr, Cu, Zn	As, Cr, Cu, Zn

Table 13. THQ estimation of fishery

Element	Cd	Pb	Cr	TTHQ
Callinectes amnicola	0.33	0.19	0.93	1.45
Sarotherodon melanotheron	0.52	0.34	0.92	1.78

Target Hazard Quotient (THQ)

The THQ of *S. melanotheron* and *C. amnicola* were evaluated using three elements (Cd, Cr, and Pb). Furthermore, chromium was evaluated based on its concentrations in the studied organisms (*C. amnicola* and *S. melanotheron*), while cadmium and lead were calculated based on the potential ecological risk index values. As a result, the THQ values for the corresponding elements in both organisms were less than one (Table 13).

Discussion

Physio-chemical parameters

The average pH of water samples taken from the Korle Lagoon was 6.61, while that from Kpeshie was 7.55. These showed that Kpeshie Lagoon was neutral to basic and Korle Lagoon was slightly acidic. Therefore, water pH in both lagoons was within the range of 6.5 to 8.5, which is considered acceptable (US EPA 2004; WHO 2005). A comparable investigation carried out by Addo et al. (2011) found that the average pH of the water in Kpeshie Lagoon was 7.8, comparable to this study's results. Therefore, within US EPA limits of 6 to 9, the sediment pH in the recorded Korle and Kpeshie Lagoons was acceptable.

While the water in Kpeshie varied from 30 to 31°C, the temperature at Korle Lagoon was between 28.9 and 30.1°C; these are typical of shallow tropical coastal lagoons, where the temperature ranges between 25 and 35°C (Biney 1990), the dissolved oxygen mean concentration in the lagoon water of Korle measured 1.86 mgL-1, while that of Kpeshie Lagoon measured 4.58 mgL^{-1}. That was a sign that the DO level in the lagoon at Korle was too low to support any possible aquatic life. Karikari et al.'s (2009) investigation into the water quality characteristics at the Korle Lagoon estuary data showed a DO level of 1.93 mgL^{-1}; this result is consistent with the current study. On the other hand, Kpeshie Lagoon was very close to the legal limit of 5 mgL^{-1}. This could explain the lagoon's fisheries did not develop. Mangroves are also covered in the Kpeshie Lagoon, which helps to oxygenate the water there. Similar research conducted by Addo et al. (2011) found DO to be 2.42 mgL^{-1}, which is not consistent with the results of the current investigation. That may be due to the Kpeshie Lagoon receiving less phosphorus in recent years.

The lagoons' mean TDS measurements were very high (28415 mgL^{-1} at Korle and Kpeshie Lagoons, respectively), exceeding the US EPA's (2004) recommendation of 1000 mgL^{-1} by a factor of 20. These suggested a high ion concentration in the lagoons, which might prevent the growth of aquatic life. The sources of these ions may include the organic and inorganic materials found in industrial wastewater, sewage discharge, or runoff from dumping sites for waste and discarded materials that are close to the lagoons. High ion concentrations could be corrosive and make lagoonal water unfit for domestic, industrial, or agricultural use (Oram 2014). a study by Apau et al. (2012) at Kpeshie Lagoon showed a range of TDS and conductivity values of 24.1-45.4 gL^{-1} and 54.8-101.8 Sm^{-1}, respectively. These numbers are comparable to the results of recent research.

The increase in conductivity with TDS has been noticed. R2, the regression coefficient, showed that most of the points fell along the regression line. The number of dissolved salts and metals in the surface water is indicated by conductivity. In the current study, the conductivity level of water samples from Kpeshie Lagoon was lower than that from Korle Lagoon. This may be because there aren't any significant industrial discharge facilities or waste dump sites close to the Kpeshie Lagoon. The mean conductivity values of both lagoons were higher than the US EPA's secondary surface water guideline. Furthermore, in Korle Lagoon, Addo et al. (2011) found a mean conductivity of 47040 Scm^{-1}. Aglanu and Appiah (2014) also found conductivities range at Kpeshie Lagoon from 19370 to 28500 Scm^{-1}. Those mean conductivity values agree with the results of the current investigation.

Heavy metal concentrations in water, sediments, crab, and fish

In both lagoons, the levels of heavy metals in water samples were lower than in sediments. Due to sediments' role as a temporary sink for heavy metals, this may have occurred (Sparks 2005). Long residence times and slow lagoon flushing rates may be responsible for low levels of heavy metals found in water samples from both the Korle and Kpeshie water sources. In the only place where the fish species *C. amnicola* and *S. melanotheron* were harvested, their metal concentrations were higher than those of the water column.

Arsenic

Concerning all sampling locations and all other metals examined in the study lagoons, arsenic concentrations were found to be the lowest. The mean arsenic concentrations in Korle and Kpeshie's water column were less than the 10 gL^{-1} thresholds the World Health Organization set in 2005.

The average As concentration in the sediments of the Korle Lagoon was 0.4906 $mgkg^{-1}$, while it was 0.5045 $mgkg^{-1}$ in the sediments of Kpeshie. The mean values fell within the Canadian Council of Ministers of the environment's (CCME 2001) limit of 7.24 $mgkg^{-1}$ for the Sediment Quality Guideline (SQG). Similar trends in both lagoons were observed in As concentrations in sediment values. These results suggested that there was no direct anthropogenic input of arsenic into either lagoon. However, the recycling and burning of electronic waste at the lagoon's banks may be to blame for the current levels of As in both lagoons.

The mean concentrations of arsenic in *C. amnicola* and *S. melanotheron* were 0.2879 $mgkg^{-1}$ and 0.3971 $mgkg^{-1}$, respectively. While *S. melanotheron*'s mean arsenic level exceeded the allowed limit of 0.26 $mgkg^{-1}$ (FAO/WHO 2011), *C. amnicola*'s mean arsenic level was below the recommended limit of 0.50 $mgkg^{-1}$ (US EPA 2010). Arsenic levels in *S. melanotheron* exceeded the threshold value despite being low in sediments from Kpeshie Lagoon. The transfer of heavy metals from one species of organism to another is probably to blame for this.

Cadmium

One of the most harmful heavy metals that can cause health issues in people is cadmium, according to Manahan (2000). According to the study, the average Cd concentration in the water column of the Korle Lagoon was 0.036 mgL^{-1}, whereas the Kpeshie Lagoon had a reading of 0.048 mgL^{-1}. Compared to WHO (2005), the mean levels of heavy metals were higher than the safe level of 0.003 mgL^{-1} for surface water. Aglanu and Appiah (2014) found 0.001 mgL^{-1} of Cd in the water of the Korle Lagoon, which is less than what was found in the current study. That might signify a rise in Cd contamination in the catchment area.

The cadmium in the sediment core at Korle Lagoon gradually decreased throughout a 0-cm depth. In the sediment of the Korle Lagoon, the first 10 cm revealed extremely high Cd concentrations, and the final 20 cm revealed a relatively stable trend. Due to increased municipal and industrial wastewater discharge, the trend in concentrations may indicate that cadmium's anthropogenic input into Korle Lagoon has quadrupled in recent years (Boadi and Kuitunen 2002).

On the other hand, Kpeshie Lagoon was relatively stable, with Cd concentrations ranging from 7.63 $mgkg^{-1}$ to 10.28 $mgkg^{-1}$. The only possible source of cadmium in Kpeshie Lagoon is urban waste or runoffs since there are no manufacturing facilities nearby.

The mean Cd concentrations in *C. amnicola* and *S. melanotheron* were 4.60 $mgkg^{-1}$ and 1.10 $mgkg^{-1}$, respectively. For fish and crustaceans, these mean values were higher than the permissible limits of 0.5 $mgkg^{-1}$ set by the US EPA in 2010 and 0.05 $mgkg^{-1}$ by FAO/WHO in 2011. In an earlier investigation by Fianko et al. (2013), the cadmium concentration in tilapia at Kpeshie Lagoon was Below the Detection Limit (BDL). Given that some fish samples read below the detection threshold in the current study, this is comparable.

Chromium

According to the USGS (1996), chromium has no known health benefits for people or animals. Hexavalent chromium poses a threat to human health and is toxic. Chromium concentrations decrease as pH and water hardness increase (Codex 1995). While Kpeshie Lagoon's mean chromium concentration was slightly above the WHO limit, Korle Lagoon's average concentration was below the permissible limit of 0.05 mgL^{-1} (WHO 2005). Chromium levels found in Kpeshie's water column are comparable to those in Apau et al. (2012).

Within the SQG recommended limit of 52.3 $mgkg^{-1}$, chromium levels in sediments from the Korle and Kpeshie Lagoons were generally found (CCME 2001). Compared to sediment concentrations in Korle Lagoon, those at Kpeshie Lagoon have higher and more stable chromium concentrations. The runoff from the Agbogbloshie market may be the source of chromium in the Korle Lagoon. In contrast, wastewater from the hospitality sector may be the source of chromium in the Kpeshie Lagoon.

Chromium was measured at 39.52 $mgkg^{-1}$ in *C. amnicola* as opposed to 5.88 $mgkg^{-1}$ in *S. melanotheron*. Compared to tilapias, which are pelagic and filter feeders, it is more exposed to higher levels of heavy metals in the benthos as a crustacean benthos bottom feeder (Signor and Vermeij 1994). Metal levels in *C. amnicola* and *S. melanotheron* were above the standard limits of 0 $mgkg^{-1}$, even though sediment metal concentrations were within the standard ranges (US EPA 2010).

Copper

Copper is a crucial element needed for metabolic processes. Furthermore, the copper amount found in the water column of the Korle and Kpeshie Lagoons was less than the WHO-recommended limit of 2.0 mgL^{-1}. In the lagoonal water of Korle, 0.049 mgL^{-1} was discovered by Aglanu and Appiah (2014) in a similar study.

Copper concentrations were higher in the sediments than the 18.7 $mgkg^{-1}$ SQG recommended limit. Both lagoons' sediments revealed a rise in copper levels in recent years. These may be caused by the burning of tires from cars or electronic waste at the edges of both lagoons. Klark et al. (2012) at Kpeshie found varying copper concentrations between 21 and 51 mg kg^{-1}, similar to the current study's trend.

The *S. melanotheron* averaged 3.49 $mgkg^{-1}$, whereas *C. amnicola* measured higher copper concentrations with an average of 31.09 $mgkg^{-1}$. The permissible limits for tilapias and crustaceans, respectively, are 20 $mgkg^{-1}$ and 70 $mgkg^{-1}$, according to FAO/WHO and the US EPA, respectively. Because the element is necessary for normal metabolic functions and is essential to organism health, copper levels in *C. amnicola* and *S. melanotheron* were within the allowable limit (USGS 1996).

Lead

Average lead concentrations in both lagoons' water columns were 0.62 mgL^{-1}, which is higher than the WHO-(2005) permissible limit of 0.01 mgL^{-1}. However, the mean lead concentrations in lagoonal water were lower than those in the sediments.

A different pattern was observed in the sediments of the Korle and Kpeshie Lagoons. Lead sediment levels in the Korle Lagoon were largely stable but have risen recently. On the other hand, Kpeshie Lagoon saw a decrease in concentration in recent years. In addition, the lead values were higher than the SQG limit that the CCME had recommended. These might indicate a rise in the amount of e-waste recovered in the Korle Lagoon catchment areas and atmospheric input from vehicular activity.

The *S. melanotheron* had an average lead concentration of 1.23 $mgkg^{-1}$ and *C. amnicola* of 10.9 $mgkg^{-1}$. These lead levels in tilapia and crustaceans were higher than the recommended limit of 1 $mgkg^{-1}$ (FAO/WHO 2011). Crustacea recorded higher metal concentrations than tilapia. This observation might be brought about by significant physiological variations in how their bodies operate. Additionally, the variation shows how much a particular species can take in from the water around it, especially in the form of sediments while feeding (Olowu et al. 2010).

Zinc

Zinc is necessary for metabolism and advantageous; it appears safe even at relatively high concentrations of 20,000-40,000 mgL^{-1}. Low values of 0.07 mgL^{-1} and 0.09 mgL^{-1} for zinc were found in the water column of the Korle and Kpeshie Lagoons, respectively. The concentrations were under the allowable 3 mgL^{-1} limit (WHO 2005). a study by Addo et al. (2011). Similar trends in zinc concentrations were found in a 2011 study done in the water of the Kpeshie Lagoon.

Higher zinc concentrations were found in the sediments of both lagoons than in the water column. Even though the levels of zinc were high, most of the concentrations were below the SQG limit of 124 mgkg-1, which is advised (CCME 2001). The measured concentrations may be related to urban runoff from nearby slum areas like Sodom and Gomorrah, tire burning along lagoon banks, and continued use of dry cells and construction materials.

The *S. melanotheron* and *C. amnicola* had average zinc concentrations of 23.23 $mgkg^{-1}$ and 36.04 $mgkg^{-1}$, respectively. These concentrations were within the recommended limits of 80 $mgkg^{-1}$ for crustaceans and 40 $mgkg^{-1}$ for tilapias, respectively (FAO/WHO 2011). Accordingly, there was no zinc contamination. These organisms' metabolic processes have probably used zinc, an essential element.

Pollution indices

Most of the estimated Cf values for the investigated heavy metals (As, Cr, and Cu) were less than one, indicating a low level of contamination. However, the values (Cf) for zinc revealed a moderate contamination factor, while those for Cd and Pb revealed a high level.

Additionally, the levels of contamination (CD) in Korle and Kpeshie showed a similar pattern to the contamination factor, with As, Cr, and Cu recording low levels of contamination. In the majority of the study sites, the PLI values were discovered to be generally high (>1). The data sets suggested that both lagoons' sediments were seriously contaminated with Cd and Pb.

Target Hazard Quotient

THQ calculated about Cd, Cr, and Pb in *C. amnicola* and *S. melanotheron* were less than one. A THQ (<1) indicates that heavy metals might not pose any non-carcinogenic health effects to consumers. The chromium THQs were very close to one, however, for both *C. amnicola* and *S. melanotheron*. Therefore, for the time being, daily consumers of crab and tilapia may not experience any non-carcinogenic health effects from chromium, but caution should be taken with the consumption rate.

In conclusion, the current research discovered the pollution in Korle and Kpeshie Lagoon was contaminated. However, just enough dissolved oxygen is present in the Kpeshie Lagoon to support fisheries. The analysis results show that the lagoon waters in both locations are contaminated with cadmium and lead. That indicates fewer environmental regulations and more domestic, municipal, and industrial waste are dumped into these lagoons. Arsenic, copper, and zinc concentrations among the heavy metals examined were low (US EPA 2004; WHO 2005). The sediments of both lagoons are heavily contaminated with chromium and copper and lead to varying degrees. Cadmium and lead were ranked as high contaminants in the sediments by the degree of contamination. Both lagoons are extremely contaminated with cadmium and lead, according to the ecological potential risk index calculated on the levels of sediments heavy metals. The cadmium, chromium, and lead metal high concentrations were found in the tissues of tilapia and crustaceans due to fish analysis in the Kpeshie Lagoon. In addition, the current study found that, except for arsenic, *C. amnicola* had higher metal concentrations than *S. melanotheron* (Cr, Cd, Cu, Pb, Zn). THQ calculated that the levels of metals in fishery resources were less than one (1) based on the values of the heavy metal concentrations in *C. amnicola*, *S. melanotheron*, and the rank of the ecological potential Risk Index (RI). That indicates people who regularly eat tilapia and crab from Kpeshie Lagoon are safe from non-carcinogenic health effects. However, the cadmium, chromium, and lead levels, which have no nutritional value, tend to bioaccumulate, so it's best to keep intake under control.

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