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The concentrations of five heavy metals in components of an economically important urban coastal wetland in Ghana: public health and phytoremediation implications

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Abstract Sakumo II is an urban wetland and a receptacle for domestic and industrial wastes from two cities in Ghana. It however supports viable populations of fish and crabs, is cultivated for food crops and grazed by farm animals. Components of the wetland can therefore accumulate pollutants, but the public health and phytoremediation implications of this are yet to be evaluated. We analysed Cd, As, Hg, Cu and Pb in the lagoon water, sediment, green algae, eight species of aquatic macrophytes, seven species of arthropods and one species of fish. The concentrations of Pb were generally below detection limit whilst Cu was detected only in the lagoon water and *Pheropsophus vertialis*. Cadmium ranged from 21±4 ppb in algae to 69±12 ppb in *Typha domingensis* and was generally higher than As and Hg. The highest concentration of As was 11.7±2.1 ppb in *Pistia stratiotes* whilst Hg was highest in lagoon water (4±2 ppb). The Cd concentrations generally, and Hg concentrations in macrophytes, were higher than US EPA guidelines indicating the wetland's resources were unsafe for regular consumption. Among the emergent aquatic macrophytes, *T. domingensis*, *Ludwigia* sp. and *Paspalum vaginatum*, respectively, had the highest accumulation capacity for Cd, As and Hg, but the floating aquatic plant *P. stratiotes* appeared to be a better accumulator of Cd and As.

Keywords Heavy metals · Macrophytes · Accumulation · Public health · Wetland · Phytoremediation

Introduction

Heavy metal contamination is of paramount concern globally because metals persist in the environment and present a number of ecological risks (Li et al. 2004; Liu et al. 2003; Radha et al. 1997). Generally, the concentrations of heavy metals in natural ecosystems are low but with deposits from anthropogenic sources; these concentrations can increase considerably (Klake et al. 2013). Among the anthropogenic sources of heavy metals are industrial and domestic waste discharges including traffic-related emissions such as vehicle exhaust, brake linings, tyre wear, asphalt wear, gasoline and oil leakage (Karvelas et al. 2003; Sorme and Lagerkvist 2002).

Wastewater treatment plants, to a large extent, control the discharge of heavy metals to water bodies, but in the West African region where these treatment plants are essentially non-existing, untreated industrial and urban sewage are frequently discharged into storm water canals and find their way to wetlands (Affian et al. 2009; Amatekpor 1998; Kouadio and Trefry 1987). Unfortunately, many large cities in the West African subregion are situated close to wetlands, and therefore, urban wetlands frequently receive untreated industrial waste, domestic sewage and storm water which can potentially increase their heavy

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metal loads (Milliman and Farnsworth 2011; Amatekpor 1998; Kouadio and Trefry 1987).

At the same time, many urban wetlands in the West African Region also support viable populations of fish and crabs on which communities depend and are cultivated for food crops, and grazed by farm animals (Gbogbo et al. 2008; Schuyt 2005; Willoughby et al. 2001). Thus, organisms inhabiting urban wetlands in West Africa may bioconcentrate heavy metals which would pose health hazards to the consumers. A comprehensive study of heavy metal levels in the biotic components of West African urban wetland ecosystems is generally missing. Whilst studies of heavy metal concentrations can lead to the identification of species for bioremediation and mitigation of public health problems, the isolated studies of heavy metal pollution in West African wetlands are generally restricted to sediment, fish and water (Acheampong et al. 2014; Klake et al. 2013; Laar et al. 2011). Wetland organisms such as plankton, macrophytes, insects, crabs and fish can be linked to the human food chain, and therefore, a holistic assessment of the heavy metal content of the components of urban wetland ecosystems would help wetland researchers and other stakeholders to determine the public health implication of the dependency on food chains connected to specific urban wetlands.

This study presents the levels of five heavy metals, namely Cd, As, Hg, Pb and Cu, in some biotic and abiotic components of an economically important urban coastal Ramsar site in Ghana. Four of these metals, namely Pb, Cd, As and Hg, are among the most toxic heavy metals found in the environment (WHO 2010). We predict that the concentrations of these heavy metals are high in all components of the wetland as a result of the wetland's function as a receptacle for domestic and industrial waste from the city of Accra and Tema and that the concentrations of these heavy metals may be of major public health concern to the wetland resource users.

Materials and methods

Study area

The study was carried out at Sakumo II Lagoon (5° 37′ N, 0° 02′ W), an urban coastal wetland located in the Tema Metropolitan Area in Ghana, West Africa (Fig. 1). Sakumo II is situated in an area that has one of the highest urban growth rates within the coastal zone of Ghana and is one of the few 'green' areas left in the rapidly expanding Accra–Tema Metropolitan Area (BirdLife International 2012). It has a total area of 13.4 km^2 and is the third most important of Ghana's five coastal Ramsar sites (Anku 2006) supporting about 70 species of waterbirds (BirdLife International 2012; Gbogbo 2007a). It is also a habitat for 13 species of fish with *Sarotherodon melanotheron* (blackchin tilapia) constituting 97 % of the fish population (Gbogbo et al. 2008; Koranteng et al. 2000). With estimated productivity of 1207 kg fish per day (Ahulu 2009) and 90 % of the users engaging in fishing (of which 10 % are involved in catching of crabs), fisheries are of particular importance in the Sakumo II and constitute the primary source of employment and animal protein to suburban communities in its catchment (Laar et al. 2011; Gbogbo et al. 2008). The importance of this wetland as habitat for insects and grazing farm animals has been well documented (Gbogbo et al. 2014; 2012; 2008).

Sakumo II is separated from the sea by sand dunes on which the Accra–Tema coastal road and the Accra–Tema rail lines are built (Fig. 1). To prevent the road and rails from flooding, the lagoon is connected to the sea by a narrow permanently open sluice. The lagoon has its headwaters passing through the city of Accra and Tema (Fig. 1) and serve as a receptacle for waste from domestic, vehicular, industrial and commercial activities including Printex (a textiles printing company) and Johnson Wax (household cleaning and domestic pesticide manufacturing Company) (Amatekpor 1998). In addition to farming in the catchment area of the lagoon, two out of the three principal streams that feed the lagoon have been dammed and used for irrigation of farmlands. These range of factors and activities thus predispose the wetland to heavy metal pollution.

Sample collection and preparation

Samples of sediment, water, algae, aquatic macrophytes, arthropods and fish from Sakumo II were collected in the second week of January 2015 for heavy metal analysis. This period is the middle of the dry season which coincides with the peak period of human use of wetland resources in Ghana. Human use of wetland resources in Ghana is at their lowest during the rainy season when water levels are low (Gbogbo et al., 2008). The samples were collected from three locations along the longitudinal axis of the lagoon including S_1 (5° 36′ 53.84″ N, 0°

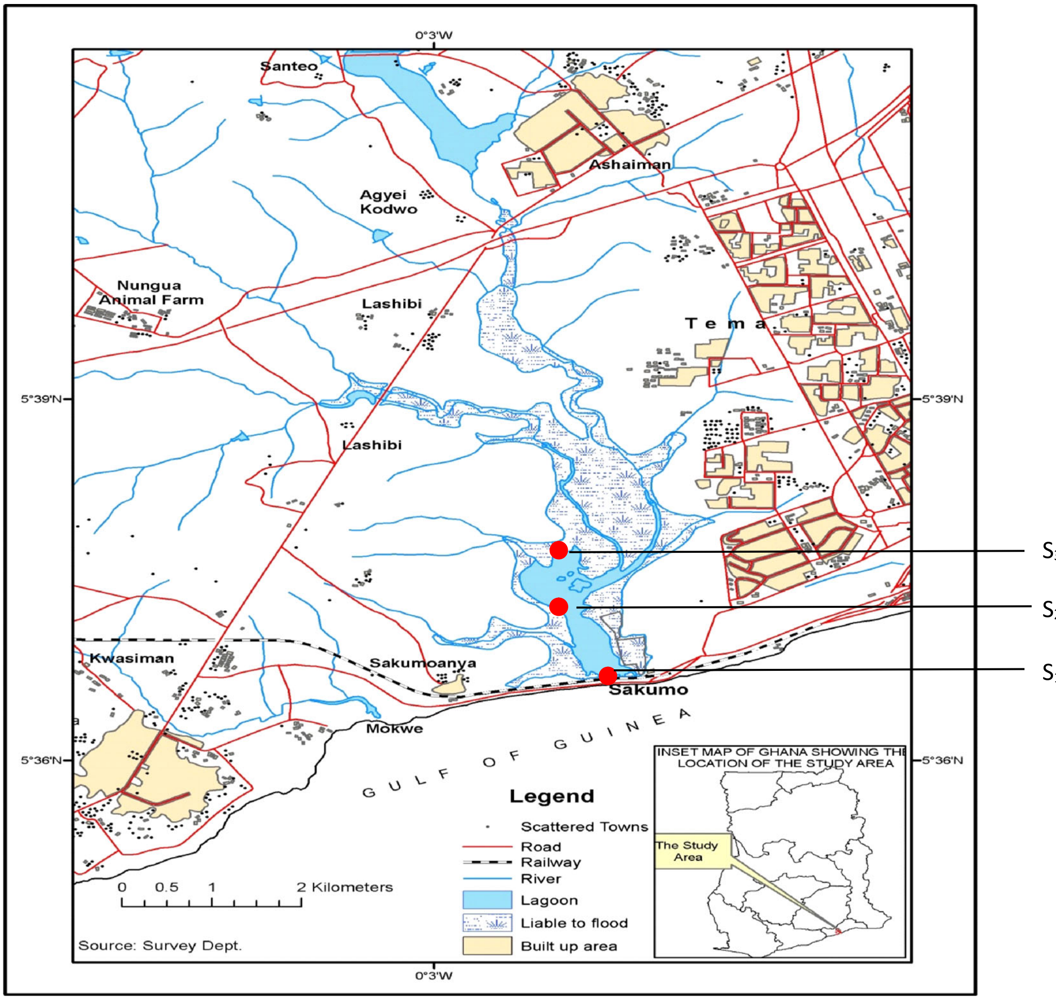

Fig. 1 Map of Sakumo II showing catchment area and sample collection points

1′ 56.31″ W—the southern end), S_2 (5° 37′ 28.00″ N, 0° 2′ 12.44″ W—the middle zone) and S_3 (5° 37′ 44.53″ N, 0° 2′ 17.66″ W—the northern end) (Fig. 1). At each location, physico-chemical properties of the lagoon water consisting of salinity, conductivity, pH, temperature, turbidity, dissolved oxygen and total dissolved solids were measured in situ using a Horiba U-52 Multi-parameter Water Quality Checker as previously described by Gbogbo (2007b). The detailed collection protocol of each sample type is described below:

Sediment and water

Sediment cores were collected at each of the three locations in triplicates, giving a total of nine cores. The cylindrical PVC corer had an internal diameter of 5 cm and was sunk to a depth of 10 cm at each location. The triplicate sediment core from each location was combined to form composite samples that were placed in acid-washed plastic containers and therefore presenting three composite sediment samples (one each for S_1, S_2 and S_3). Similar to the sediment core sampling technique, 50 ml of lagoon water samples was collected in triplicate at a depth of about 10 cm in each of the three locations. The triplicate samples from each location were combined to form 150 ml composite water samples in acid-washed plastic containers. The water samples were filtered through No. 1 Whatman paper and acidified to 1 % nitric acid (*v*/*v*).

Algae

Using a scoop net of 300 μm mesh, samples of green algae floating on the lagoon water were collected from the vicinity of each of the three locations. The collected algae from each location were emptied onto separate acid-washed plastic containers and transported to the laboratory where they were washed with deionized water and debris removed. The washed algae were filtered over No. 1 Whatman paper and air dried on petri dishes.

Aquatic macrophytes

The shoots (stem and leaves) of aquatic vegetation on the wetland were collected along the marshy flood plain of the lagoon. Plant roots were not analysed because grazing animals on the wetland would usually forage only on the shoots of the plants, and therefore, roots would not contribute directly to the dynamics of heavy metals in food chain connected to the wetland. For each identified plant species, three specimens were collected from each of the three locations and, thus, giving a total of nine specimens per species based on availability. The collected aquatic macrophytes were identified and washed with deionized water after which they were placed in plant press for 3 days prior to chemical analysis.

Insects and arachnids

Insects and arachnids were collected from each of the three locations on the wetland using pitfall traps. The insect and arachnid specimens were transported to the laboratory in acid-washed plastic jars after which they were identified, washed with distilled water and air dried on petri dishes.

Fish and crabs

Approximately 1 kg of fish was purchased from fishermen on the wetland. The fish samples which consisted of only *S. melanotheron* were thoroughly mixed after which 15 individuals were selected at random, washed with deionized water and air dried on acid-washed petri dishes. Similarly, 10 specimens of rainbow crab *Cardisoma armatum* were purchased from crab catchers on the wetland. The crabs were washed with deionized water for further processing.

Analysis of heavy metals

Air-dried fauna and pressed plant specimens were powdered in porcelain mortars with pestles to produce homogenized materials. Approximately 0.1 g of each homogenized material was digested with concentrated sulphuric and hydrogen peroxide following the Digesdahl digestion procedures (Hach Company 1997). Similarly, 5 ml of each lagoon water sample was digested with concentrated sulphuric and hydrogen peroxide just as 0.1 g of the sediment. Three reagent blanks were also prepared. The digested materials were filtered with No. 1 Whatman filter paper into round-bottomed flasks and diluted to 100 ml with deionized water after which aliquots were analysed for Cd, Hg, Cu and Pb using Perkin Elmer AAnalyst 400 Atomic Absorption Spectrometer. Arsenic was analysed using the PinAACle 900T Flow Injection Absorption Spectrometer. Triplicate analyses were carried out to ascertain reproducibility and reliability of the data.

Data analysis

The concentration of the individual heavy metals for each specimen was derived as an average of three instrumental readings. The mean and standard error of each component was derived as an average of the mean values of specimens from the three locations ($(S_1+S_2+S_3)/3$). Mean concentration of each heavy metal was calculated for taxonomic groups of organisms including aquatic macrophytes, algae, fish, insects, arachnids and crabs. The taxonomic groups of organisms were presented in a conceptualized food chain linked to humans and accumulation trends and implications deduced. Plant–sediment accumulation factor (BAF_p) for each heavy metal was calculated for each plant except *Pistia stratiotes* which was a floating macrophyte and was therefore not in direct contact with the sediment (Liu et al. 2014). Thus, $BAF_p=C_p/C_s$ where C_p is the concentration of a particular heavy metal in plant and C_s is the concentration of a particular heavy metal in the sediment. Similarly, biota–water accumulation factor (BAF_b) was calculated for each water-dwelling species including *P. stratiotes* given that $BAF_b=C_b/C_w$ where C_b is the concentration of a particular heavy metal in the organism and C_w is the concentration of a particular heavy metal in the lagoon water (Liu et al. 2014). Observed heavy metal components were compared with US EPA Maximum Contaminant Level Goal (MCLG) and US EPA Maximum Contaminant Level (MCL).

Results

Water quality

The quality of the lagoon water as indicated by physico-chemical parameters is shown in Table 1. At the time of the data collection (the middle of the dry season), water levels in the lagoon was critically low, completely cutting off the link between the lagoon and the sea. As a result of absence of tidal effect of the sea on the wetland, the mean salinity of the wetland environment (3.40±0.11 ppt) was close to that of fresh water whilst conductivity ranged from 6.09 to 6.61 mS/cm. The mean pH (9.03±0.26) was basic whilst temperatures ranged from 29.58 to 31.59 °C. Turbidity on the wetland varied widely from 120 to 290 NTU whilst mean dissolved oxygen and total dissolved solids were 7.87±1.55 mg/L and 3.95±0.09 g/L, respectively.

Description of collected specimens

Seventeen species of organisms including algae, eight species of aquatic macrophytes, seven species of arthropods and one species of fish were collected and analysed. The species of plants analysed include *Typha domingensis* (southern cattail), *Paspalum vaginatum* (silt grass), *Ludwigia* sp. (water primrose), *Alternanthera* sp. (Joyweed), *Ipomoea pes-caprae* (beach morning glory), *Cyperus* sp. (umbrella-sedges), *P. stratiotes* (water lettuce) *and Sesuvium portulacastrum* (shoreline purslane). The arthropods consisted of a species of arachnid, *Heteropoda ventoria* (pantropical huntsman spider), a species of crustacean, *C. armatum* (Rainbow Crab) and five species of insects consisting of *Pheidole* sp. (big-headed ant), *Pheropsophus vertialis* (Bombardier beetle), *Abedus lutarium* (Giant water bug), *Hydrophilus triangularis* (giant water beetle) and an unidentified species of insect belonging to the family Calliphoridae. The species of fish was *S. melanotheron* (blackchin tilapia).

Table 1 Physico-chemical parameters of the lagoon water at Sakumo II Ramsar site

Parameters	Minimum	Maximum	Mean±SD
Salinity (ppt)	3.3	3.5	3.40±0.11
Conductivity (mS/cm)	6.09	6.41	6.26±0.15
pH	8.88	9.48	9.03±0.26
Temperature (°C)	29.58	31.59	30.43±0.78
Turbidity (NTU)	120	290	210±61
Dissolved oxygen (mg/L)	4.72	8.82	7.87±1.55
Total dissolved solids (g/L)	3.84	4.04	3.95±0.09

Concentration of heavy metals

Among the heavy metals analysed, Cd, As and Hg were detected in most components of the wetland ecosystems (Fig. 2). Concentrations of Pb in all the materials analysed were below detection limit. Similarly, the concentrations of Cu in all the samples except the lagoon water (30±12 ppb) and *P. vertialis* (3±1 ppb) were below the detection limit of 0.15 ppb.

Cadmium

The concentrations of Cd ranged from 21±4 ppb in algae to 69±12 ppb in *T. domingensis* and were higher in all the components of the wetland ecosystem than the other heavy metals (Fig. 2). Cadmium concentration in the sediment (43±8 ppb) was higher than the lagoon water (24±6 ppb). Also, Cd concentrations in all the biotic components of the wetland except the algae were higher than in the water (Fig. 2).

The plant–sediment accumulation factor (BAF_p) of Cd for each species of plant was greater than one with the exception of *Alternanthera* sp. and *Ludwigia* sp. (Table 2). *T. domingensis* recorded the highest BAF_p for Cd (1.6) whilst the lowest BAF_p for Cd was recorded by *Ludwigia* sp. (0.88). BAF_b for Cd among the water-dwelling organisms (Table 2) on the wetland ranged from 1.21 for *H. triangularis* to 2.67 for *C. armatum.*

Arsenic

Arsenic concentrations in Sakumo II were generally lower than Cd but higher than Hg, Cu and Pb (Fig. 2). The As concentration in the sediment (6.67±1.6 ppb) was higher than the lagoon water (4.39±1.2 ppb) whilst As levels were below the detection limit of 0.02 ppb in the algae, *C. armatum* and *S. melanotheron.* Beyond these three biota, the concentrations of As in the rest of the components were higher than the lagoon water and sediment. The highest concentration of Arsenic was measured in *P. stratiotes* (11.72±2.1 ppb) (Fig. 2). BAF_p of As values were all greater than one except for *Cyperus* sp. (Table 2). The highest BAF_p of As was

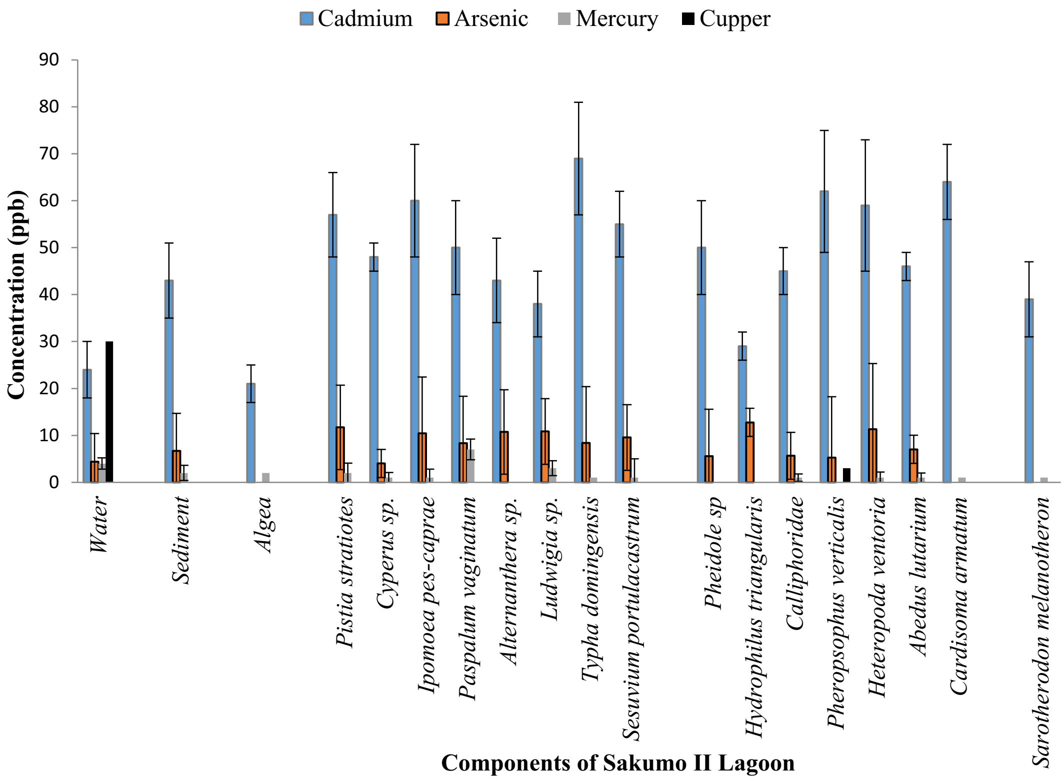

Fig. 2 Concentration of cadmium, arsenic, mercury and cupper in components of Sakumo II Lagoon

recorded for *Ludwigia* sp. With regard to the water-dwelling biota, BAF_b of As ranged from 1.60 for *H. triangularis* to 2.67 for the floating vegetation, *P. stratiotes* (Table 2).

Mercury

Mercury concentrations in components of the wetland ranged from 1 to 4 ppb with concentrations in *Pheidole*

Table 2 Bioaccumulation factor (BAF) of plant and aquatic organisms inhabiting Sakumo II in Ghana

Species name	Plant–sediment accumulation factor (BAF_p)			Biota–water accumulation factor (BAF_b)		
	Cd	As	Hg	Cd	As	Hg
Typha domingensis	1.6	1.24	0.5			
Ipomoea pes-caprae	1.4	1.54	0.5			
Sesuvium portulacastrum	1.28	1.43	0.5			
Paspalum vaginatum	1.16	1.23	3.5			
Cyperus sp.	1.12	0.59	0.5			
Alternanthera sp.	1	1.59	0			
Ludwigia sp.	0.88	1.6	1.5			
Cardisoma armatum				2.67	–	–
Pistia stratiotes				2.38	2.67	0.5
Abedus lutarium				1.92	1.60	0.25
Sarotherodon melanotheron				1.63	–	0.25
Hydrophilus triangularis				1.21	2.91	

sp. and *H. triangularis* lower than the detection limit of 1 ppb. The Hg levels in the components of the wetland were generally low with the concentration in the sediment (2±1.6 ppb) being lower than in the water (4±2 ppb) contrary to the observations for Cd and As. BAF_p of Hg for each plant species was less than one except for *P. vaginatum* and *Ludwigia* sp. Similarly, BAF_b of Hg for each of the water-dwelling species was lower than one (Table 2).

Food web and accumulation trends of heavy metals

Figure 3 shows a conceptualized food web of the taxonomic group of organisms obtained from the faunal survey together with the mean concentration of each heavy metal in the taxonomic groups. In conceptualizing the food web, it was assumed that fish do not feed on insects and arachnids because *S. melanotheron*—the only species of fish obtained—feeds on only plankton and benthic diatom (Pauly, 1976). The figure indicated Cd concentration in the biotic components of the wetland to be in the order crab>macrophytes>insect and arachnids>fish>algae. Also, whilst the As concentration in macrophytes was higher than the insects and arachnids at the higher trophic levels, As concentrations along the algae–fish–crab food chain was below detection limits. Similarly, Hg concentrations were higher in the producers than the consumers at higher levels even though the Hg concentrations were generally low.

A comparison of the concentration of the Cd with US EPA guidelines (Table 3) indicated Cd concentrations in all the components of Sakumo II were higher than the US EPA guidelines. In contrast, the concentrations of As were generally lower than the US EPA guidelines, although the mean concentration of As in macrophytes was very close to the MCL. Also, Hg concentrations in macrophytes and water were higher than the US EPA guidelines.

Discussion

General comparison of the measured heavy metal concentrations

Heavy metals persist in the environment and present a number of ecological risks as a result of which their contamination is generally treated as a serious environmental issue (Li et al. 2004; Liu et al. 2003; Radha et al. 1997). Of the five heavy metals analysed in this study, Cd concentration was the highest followed in decreasing order by As, Hg, Cu and Pb at Sakumo II. Comparatively, the concentrations of the heavy metals in this study are comparable with those reported earlier for water and sediment in Sakumo Lagoon (Laar et al., 2011) but lower than those reported by Acheampong et al. (2014) for some other urban lagoons in Ghana. The study of Acheampong et al. (2014) however involved extremely polluted urban lagoons that are considered to be no longer supporting aquatic life (Gordon et al. 1998). Further, the concentrations reported in this study are lower than those previously reported in water and sediment from mining areas in Ghana (Serfor-Armah et al. 2006; Akabzaa et al. 2007). Clearly, despite the functions of Sakumo II as a receptacle for waste from the city of Accra and Tema, the extent of its heavy metal pollution is well below the levels recorded for wetlands in the mining areas in the country.

Laar et al. (2011) reported higher concentrations of some heavy metals in the sediment of Sakumo II compared to the lagoon water. The results of this study are consistent with Laar et al. (2011) in terms of Cd and As. On the contrary, this study indicated that Hg in the lagoon water of Sakumo II was higher than in the sediment. The solubility of the metals in water is controlled by several physical and chemical conditions including the prevailing physico-chemical characteristics. Indeed, the measured physico-chemical parameters in this study differ from Laar et al. (2011) whose samples were collected under a neutral pH (7.69), a higher salinity (11.29 ppt) and a higher dissolved oxygen level (11.32 mg/L) as compared to pH, salinity and dissolved oxygen values of 9.03, 3.4 ppt and 7.87 mg/L, respectively, in this study. The differences in the prevailing physico-chemical properties under which the samples were collected could account for the difference in the concentrations of the metals between the sediment and water phases.

It is worth noting that the differences in the heavy metal concentrations in the sediment and water phases in this study are generally close. This closeness of the concentrations of metals in sediment and water phases in Sakumo II had earlier been recorded by Laar et al. (2011), therefore confirming that the concentration of heavy metals in sediment and water phases are indeed close in Sakumo II.

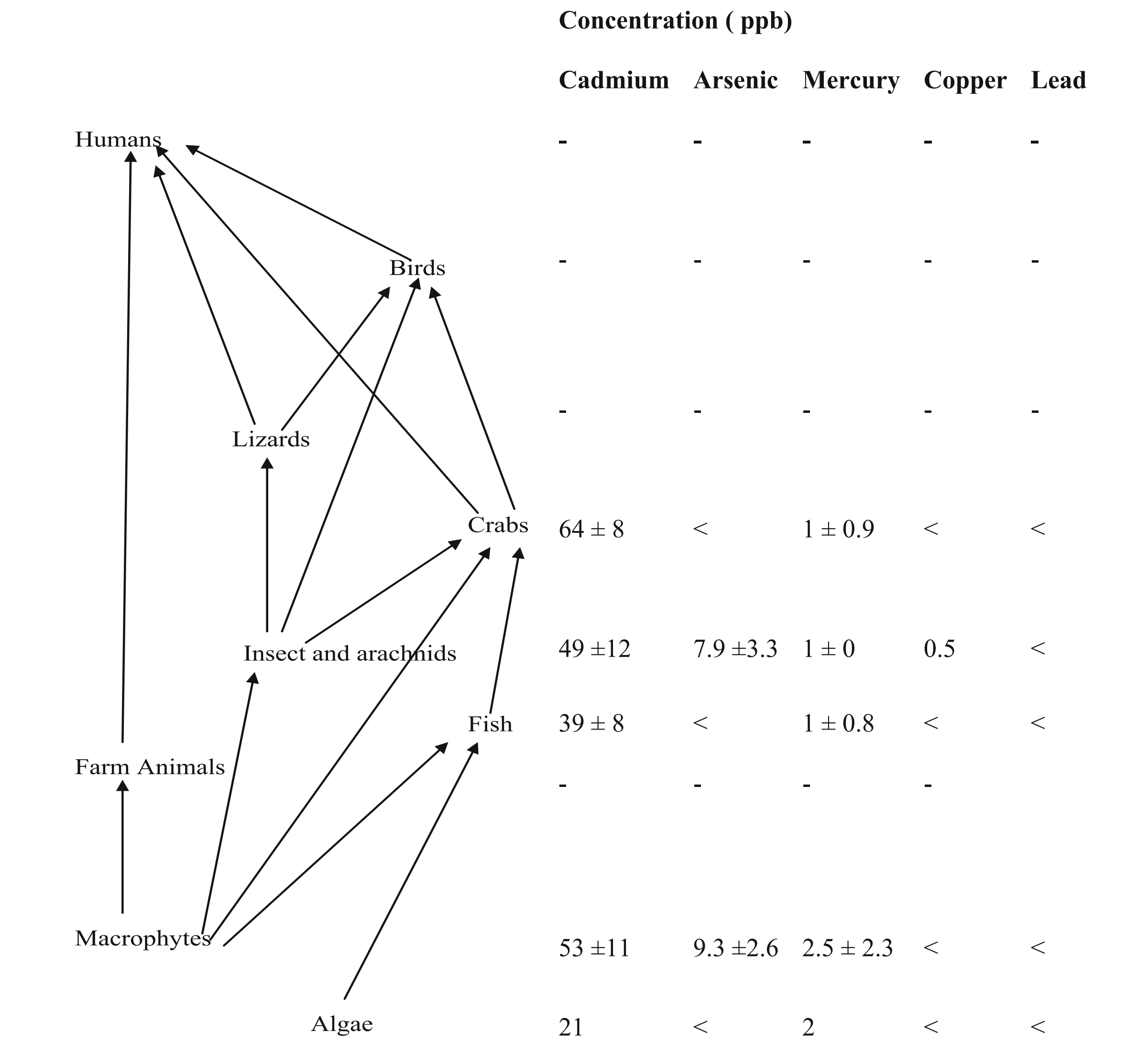

Fig. 3 A conceptualized food web at Sakumo II indicating the concentrations of Cd, As, Hg, Cu and Pb. (< indicates values were less than detection limits)

Table 3 Comparison of observed concentrations of heavy metals in some component of Sakumo II Lagoon with US EPA guidelines

	Concentration (ppb)				
	Cd	As	Hg	Cu	Pb
US EPA Maximum Contaminant Level Goal (MCLG)	5	0	2	1300	0
US EPA Maximum Contaminant Level (MCL)	5	10	2	–	–
Concentration in lagoon water	24±6	4.4±1.2	4±2	4±2	
Concentration in *Sarotherodon melanotheron*	39±8	–	1±0.8	–	–
Concentration in *Cardisoma armatum*	64±8	–	–	–	–
Mean concentration of emergent macrophytes	53±11	9.3±2.6	2.5±2.3	–	–

Phytoremediation considerations

The sediment remains the principal source of heavy metals for the emergent aquatic macrophytes whilst the lagoon water constitutes the major source of heavy metals for the floating aquatic macrophytes. Therefore, the differences in the concentrations of heavy metals between sediment and water would have implications for the availability and accumulation of the heavy metals to biota (Liu et al. 2014).

Among the emergent aquatic macrophytes, BAF_p for Cd was in the order *T. domingensis*>*I. pes-caprae*> *S. portulacastrum*>*P. vaginatum*>*Cyperus* sp.> *Alternanthera* sp.>*Ludwigia* sp. The order of accumulation of As however was *Ludwigia* sp.>*Alternanthera* sp.>*I. pes-caprae*>*S. portulacastrum*>*T. domingensis*>*P. vaginatum*> *Cyperus* sp. Thus, whilst *T. domingensis* had the highest accumulated factor for Cd among the emergent aquatic macrophytes, *Ludwigia* sp. had the highest for As. The only emergent aquatic macrophytes that accumulated Hg from the sediment to appreciable extents were *P. vaginatum* and *Ludwigia* sp. Clearly, the different emergent aquatic macrophyte species have differential accumulation capacities for the various heavy metals (Mojiri et al. 2013; El Falaky et al., 2004) with *T. domingensis*, *Ludwigia* sp. and *P. vaginatum* having the highest accumulation capacity for Cd, As and Hg, respectively.

P. stratiotes, the only floating aquatic plant obtained in this study, had Cd concentration lower than that of *T. domingensis*. However, because *P. stratiotes* is a floating plant, the BAFb of *P. stratiotes* for Cd was higher than the BAF_p of *T. domingensis*, suggesting that *P. stratiotes* is a better accumulator of Cd than *T. domingensis*. That notwithstanding, *P. stratiotes* had a higher concentration of As than all the remaining species of aquatic macrophytes despite it not being in direct touch with the sediment that relatively had a higher concentration of As than the lagoon water. Consequently, the BAF_b value of *P. stratiotes* is higher than the BAF_p values of the emergent aquatic plants and once again highlights the significance of *P. stratiotes* in the phytoremediation of Cd and As. This supports the work of Khan et al. (2014) in his description of the potential of *P. stratiotes* in the absorption of heavy metals.

In relation to BAF_b of the water-dwelling fauna, the BAF_b values for Cd in each of the fauna was higher than one, indicating that the species of aquatic fauna accumulated Cd from their environment (Liu et al. 2014). Accumulation of Cd was in the order of *C. armatum*> *A. lutarium*>*S. melanotheron*>*H. triangularis*, therefore indicating the rainbow crab as the highest accumulator of Cd among the water-dwelling fauna. Further, whilst *H. triangularis* had the lowest accumulation capacity for Cd, it had the highest accumulation capacity for As, indicating that the accumulation capacities for the various heavy metals vary from one species of fauna to another. This may be related to differences in their modes of life including physiology and foraging.

Metals can be concentrated uniformly between roots and shoots, accumulate more in roots than in shoots or accumulate mostly in roots (Liu et al. 2014). The BAF_p values of the emergent aquatic plants in this study are based on only shoots whilst the BAF_b of *P. stratiotes* is based on the entire plant. Our inability to determine the translocation factors for the plants in this study stemmed from the fact that the major focus of the study was metal levels in consumable components of the wetland of which plant roots were unlikely. Although the results of this study highlight the comparative phytoremediation properties of the aquatic plants based essentially on their shoots, further studies on translocation factors of metals between shoots and roots of the aquatic macrophytes will provide further insight to the subject. Since the concentration of metals in the macrophytes were not very high, carrying out such a study on macrophytes inhabiting urban wetlands with higher levels of heavy metal pollution would shed further light on the phytoremediation properties of the plants.

Public health consideration

From the conceptualized food web, Cd concentrations increased from the lower trophic levels to the higher trophic levels. Although this has generally been the case for most heavy metals in the environment (Li et al. 2004; Liu et al. 2003; Radha et al. 1997), the fact that Cd concentrations in each of the components of Sakumo II was higher than the US EPA guidelines indicates that dependency on food chains connected to Sakumo II would have adverse health implications for man. The public health implication of the dependency on food resources from Sakumo II is further highlighted by the observation that macrophytes have a higher Hg concentration than the US EPA guidelines. Although As concentrations in Sakumo II were generally lower than the MCL, the concentrations of As in the macrophytes were again very close to the MCL and therefore further highlighting the health risk associated with food chains connected to the macrophytes in Sakumo II. On the contrary, Cu and Pb concentrations in Sakumo II were generally lower than MCL indicating the use of the wetland's resources would not result in health complications associated with the exposure to Cu and Pb.

Anthropogenic sources of Cd in aquatic systems generally include corrosion of galvanized pipes, discharge from metal refineries, runoff from waste batteries and paints, whilst As mainly comes from runoff from glass and electronic production wastes (USEPA 2014a; 2014b, Hutton 1984). Activities such as metal smelting, battery, glass and electronic works including e-waste processing are common in the cities of Accra and Tema (Feldt et al. 2014). These activities may be directly connected with the high concentrations of Cd and As in the wetland.

Regular consumption of Cd in excess of MCL is associated with kidney damage whilst As is linked to skin damage, circulatory system problems, and increased risk of cancer (USEPA 2014a; 2014b). Thus, besides the health risk associated with the consumption of fish and crabs from Sakumo II as a result of the higher than sevenfold MCL Cd concentrations, consumption of meat from farm animals that fed on the wetland may pose a greater risk to humans since the aquatic macrophytes in addition to tenfold MCL Cd concentrations have As concentrations very close to the MCL.

About 1207 kg of fish is harvested per day in Sakumo II (Ahulu 2009). Although the actual amount of crabs harvested from Sakumo II has not been documented, about 10 % of the users of Sakumo II are involved in catching of crabs (Gbogbo et al. 2008). These fish and crabs are sold out to the general public in the open market and restaurants. Besides, animal protein from farm animals that graze Sakumo II is sold to the general public. The high levels of Cd recorded in this study therefore bring the public health implications of these practices to attention.

Conclusions

Cadmium concentrations were the highest of five heavy metals measured in Sakumo II Ramsar site followed in decreasing order by As, Hg, Cu and Pb. The Cd concentrations in all the components of the wetland were higher than the US EPA guidelines, indicating they were unsafe for regular consumption and that dependency on food resources connected to the wetland would have serious public health implications. *T. domingensis*, *Ludwigia* sp. and *P. vaginatum* had the highest accumulation capacity for Cd, As and Hg, respectively, among the emergent aquatic macrophytes, whilst the floating aquatic plant *P. stratiotes* appeared to be a better accumulator of Cd and As. To provide further insight to the bioremediation capabilities of the wetland plants, we recommend studies on the translocation of heavy metals by the aquatic macrophytes inhabiting urban wetlands with higher metal loads.

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