Assessment of Heavy Metal Contamination and Distribution in Surface Soils and Plants along the West Coast of Ghana

B.Y Fosu-Mensah[1], A. Ofori[1], M. Ofosuhene[2], E. Ofori-Attah[2], F.K.E Nunoo[3], G. Darko[4], I. Tuffour[2], C.Gordon[1], D. K Arhinful[5], A. K Nyarko[2,6], R. Appiah-Opong[2*]

[1]*Institute for Environment and Sanitation Studies, University of Ghana, P.O. Box 209, Legon, Accra, Ghana.*

[2]*Department of Clinical Pathology, Noguchi Memorial Institute for Medical Research, College of Health Sciences, University of Ghana, P.O. Box LG 581, Legon, Accra, Ghana.*

[3]*Department of Marine and Fisheries Sciences, School of Biological Sciences, College of Basic and Applied Sciences, University of Ghana, P.O. Box LG 99, Legon, Accra, Ghana.*

[4]*Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.*

[5]*Department of Epidemiology, Noguchi Memorial Institute for Medical Research, College of Health Sciences, University of Ghana, P.O. Box LG 581, Legon, Accra, Ghana.*

[6]*School of Pharmacy, College of Health Sciences, University of Ghana, P.O. Box KB 52, Legon, Accra, Ghana.*

*Corresponding author; Email: *rappiah-opong@noguchi.ug.edu.gh*

Abstract

Onshore oil drilling activity is ongoing at Jubilee oil fields, Ghana. This activity could lead to heavy metal exposure with consequential adverse effects on public health in nearby coastal communities. Therefore, we assessed heavy metal levels and spatial distribution in soils and plants from the west coast of Ghana to obtain baseline values for monitoring heavy metal exposure. Surface soils were collected from six coastal communities, and analyzed for arsenic, cadmium, copper, mercury, lead, selenium and zinc using atomic absorption spectrophotometer. Mean heavy metal concentrations in soil samples were 2.06, 6.55, 0.016, 21.59, 0.18 and 39.49mg/kg for arsenic, copper, mercury, lead, selenium and zinc, respectively. Mean heavy metal concentrations in plants were 2.70, 17.47, 3.17, 91.74, 1.51 and 9.88mg/kg for arsenic, cadmium, copper, lead, selenium and zinc, respectively. Concentrations of arsenic, cadmium and lead in plants exceeded WHO/FAO permissible limits. Enrichment factor for arsenic was significant and extremely high for selenium, while geoaccumulation index showed moderate pollution for selenium. Soil contamination factors for arsenic, lead, and selenium indicated considerable contamination. In view of these findings remediation methods must be adopted to safeguard the communities. The data will be useful for future monitoring of heavy metal exposure in the communities and to assess the impact of the ongoing crude oil drilling activity on the environment.

Introduction

Pollution of the natural environment with heavy metals has received the attention of researchers globally. This is mainly due to their harmful effects on both plants and animals (Förstner and Wittmann 2012). Concentrations of heavy metals in coastal environment have been increasing rapidly due to human activities that culminate in their discharge into the environment (Ra et al. 2013). Activities of some industries result in release of metals into the environment which may bind with particulate matter and enter soils and sediments and plants may also pick them. Contamination of the soil ecosystem by heavy metals is a critical environmental challenge because the metals persist in the environment (Babatunde et al. 2014; Kirpichtchikova et al. 2006; Pakade et al. 2012). The soil is a major source of contamination to the food web. Thus, it is a preferred matrice for assessment of metal contamination (Ra et al. 2013). Heavy metals are ubiquitous in the soil environment. Due to rapid urbanization and industrialization of the coast of Ghana, it is anticipated that heavy metals are being continuously introduced into the environment from a variety of sources such as discharge of domestic sewage, industrial waste water, and atmospheric deposition.

Ghana officially become an oil producing country in 2010 with an initial estimated reserve of 800 million to 1.8 billion barrels and expected peak production of 120,000 barrels per day (Acquah-Sam 2014; Ayensu 2013). Prior to exploration of petroleum resources, an offshore environmental impact assessment was conducted by TDI-Brooks International in collaboration with Tullow Oil Company, Ghana, from 2008 to 2009. Therefore, it is necessary to evaluate the distribution of heavy metals in soils and plants in the coastal communities, as intensive petroleum exploration and extraction continues 60 km offshore. This study determined the spatial distribution and concentration of heavy metals in soils and plants along the south-western coast of Ghana. Different metal assessment indices such as enrichment factor, geoaccumulation index, contamination factor and pollution load index were used to evaluate the contamination status of the study area. The Environmental Protection Agency of Republic of Ghana will be informed of the communities with unacceptable levels of heavy metals. The data generated from this study will serve as baseline for future monitoring of the coastal communities for heavy metal exposure.

Methods

Study Area

The study was conducted in six districts bordering the marine coastal environment of the Jubilee Oil Field in the Western Region of Ghana. One community was selected from each district. The six (6) study communities were Atuabo in Ellembelle District, Half Assini in Jomoro District, Lower Axim in Nzema East District, Dixcove in Ahanta West District, Shama in Shama District and New Takoradi in Sekondi-Takoradi District.

The Western Region of Ghana covers an area of 23,921 km^2, which forms about 10 % of Ghana's total land size, is located in the south-western part of the country and lies between 5°23'24.7128N and 2°8'42.0864 W (Figure. 1). The total population of the region is 2,376,031 representing 9.6 % of the national population (Ghana Statistical Service 2010). The region has about 75 % of its vegetation within the high forest zone of Ghana. The southwestern

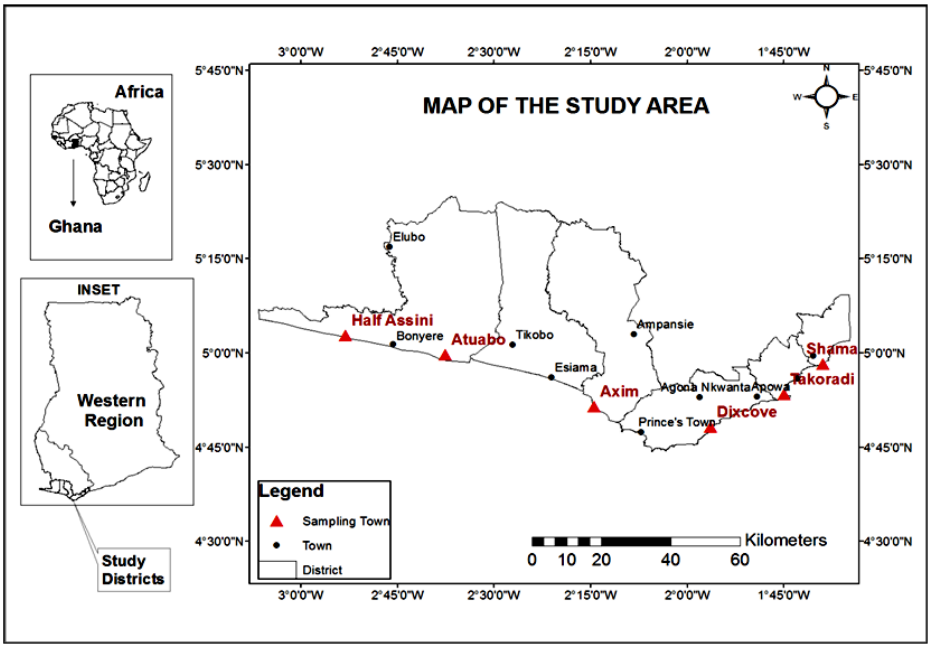

Figure 1. Map of the study area showing the coastal communities
Soil and plant sampling

part of the region is noted for rainforest interspersed with patches of mangrove forest along the coast and coastal wetlands, whereas high tropical forest and semi-deciduous forest is also found in the northern part of the region. The region lies in the equatorial climate zone characterized by moderate temperature of 22 °C to 34 °C at night and day, respectively. The region is the wettest, with bimodal rainfall pattern averaging 1600 mm per year. The rainfall peaks fall between May to July and September to October, and intermittent minor rains are experienced all year round.

Soil samples were collected in the dry season (late October) from six different communities at 0-15 cm depth. In each community, five (5) core soil samples were collected randomly, using a soil auger. Each core sample was made up of 5 composite samples that were bulked together and well mixed. Representative composite samples were collected and stored in well labeled containers and then transported to the laboratory for analysis. A portable GERMIN GPS instrument was used to take the coordinates of the sampling points. Ten wild plant species in each of the communities were collected for analysis, depending on its dominance in the communities. A total of sixty (60) plant samples were collected for analysis. The names of the common wild plants collected were *Alchonea cordifolia, Avicennia nitida, Chromolaena odorata, Erythrina senegalensis, Ficus exasperata, Ficus sagittifolia, Ficus umbellata, Terminalia catappa, Thespesia populnea, and Senna siamea.*

Sample preparation

Soil samples were air-dried for 5 days, ground using porcelain pestle and mortar, and then sieved through a 2 mm mesh. Plant samples were washed with distilled water and kept in an oven at 70 to 80 °C until constant weight was attained. The samples were then milled into a powder, sieved through a 2 mm sieve and then stored in plastic polythene bags for acid digestion prior to heavy metals determination.

Atomic Absorption Spectrometric measurement

Soil samples (1 g) were digested with 10 mL of ternary mixture $HClO_4$:HNO_3:H_2SO_4 (1:25:2.5) on a digestion block at 95 °C under a fume hood. After digestion, the samples were allowed to cool, before filtration using Whatman No. 42 filter paper. Volumes were adjusted with distilled water to 100 mL in volumetric flasks. For plant sample, 0.5 g was pre-digested, overnight, in 5 mL concentrated H_2SO_4. Samples were then digested at 95 °C on sand bath with the addition of drops of H_2O_2 until they were completely oxidized. After cooling, the digested samples were filtered into 100 mL volumetric flask and brought up to the mark with distilled water. Concentrations of heavy metals were measured using Perkin Elmer PINAAcle 900T Atomic Absorption Spectrophotometer with air-acetylene gas for cadmium (Cd), copper (Cu), lead (Pb), selenium (Se), zinc (Zn) and argon gas for arsenic (As) and mercury (Hg). Before sample analysis was done, calibration curves were prepared using the respective heavy metal standards. Triplicate measurements were performed.

Assessment of soil contamination

Contamination status of soils were determined using enrichment factor (EF), geoaccumulation index (I_{geo}), contamination factor (CF), and pollution load index (PLI). Enrichment factor of metals were determined using Equation

1 after the concentration of each metal has been normalized using aluminum (Al) as the reference element.

Where EF is the enrichment factor for the element, Cx is the concentration of element of

$$EF_x = \frac{[C_x/C_{ref}]\ \text{sample}}{[B_x/B_{ref}]\ \text{background}} \quad (1)$$

interest in sample; Cref is the concentration of the reference element used for normalization in the sample. Bx is the concentration of the element in the crust and Bref is the concentration of the reference element used for normalization in the crust (Ato et al. 2010; Cevik et al. 2009). Five contamination categories are assigned on the basis of the enrichment factor: EF<2 = deficiency to minimal enrichment; EF=2-5 = moderate enrichment; EF=5-20 = significant enrichment; EF=20-40 = very high enrichment and EF>40 = extremely high enrichment (Yongming et al. 2006).

The index of I_{geo} is widely used in the assessment of contamination by comparing the levels of heavy metal obtained to a background level originally used with bottom sediments (Atiemo 2011; Muller 1969). I_{geo} is calculated using Equation 2.

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (2)$$

where Cn is the measured concentration of the element in soil being studied and Bn represents the geochemical background concentration in fossil argillaceous sediment (crusted average or average shale) (Akoto et al. 2008). The constant 1.5 is introduced to minimize the effect of possible variation in the background values which may be attributed to lithological variation in the sediments (Lu et al. 2009). The following classification is given for I*geo*:<0 = practically unpolluted, 0-1 = unpolluted to moderately polluted, 1-2 = moderately polluted, 2-3 = moderately to strongly polluted, 3-4 = strongly polluted, 4-5 = strongly to extremely polluted and >5 = extremely polluted (Lu et al. 2009).

The level of contamination of soil by metal is expressed in terms of a CF calculated as shown in Equation 3.

where Csample is contamination of sample, Cbackground is background contamination

$$CF = \frac{C_{sample}}{C_{background}} \quad (3)$$

and the contamination factor CF<1 refers to low contamination; 1≤CF<3 means moderate contamination; 3≤CF<6 indicates considerable contamination and CF>6 indicates very high contamination.

The PLI which assesses the mutual contamination effects of the metals was computed using equation 4.

$$PLI = (CF_n \times CF_n \times CF_n \times CF_n \times CF_n \times CF_n)^{1/n} \quad (4)$$

The PLI is the ratio of element concentration in the study to the background concentration of the abundance of chemical elements in the continental crust. The PLI of each element is classified as either low (PLI≤1), middle (1<PLI≤3) or high (PLI>3) (Chen et al. 2005).

Statistical analysis

Data were subjected to statistical analysis using SPSS version 20.0. One-way analysis of variance (ANOVA) was used to test the difference in metal concentrations among the communities. The least significant difference method was applied at the probability level, *p*=0.05. Correlation of heavy metals in soil was found using 2-tailed Pearson's correlation test.

Results and Discussion

Heavy metals concentration in soil samples

Table 1 shows the mean concentrations of metals in soil at the various communities. The mean concentrations of heavy metals in soil were 2.06 mg/kg for As, 6.55 mg/kg for Cu, 0.02 mg/kg for Hg, 21.59 mg/kg for Pb, 0.18 for Se and 39.49 for Zn. The highest concentrations of Cu and Pb in soil were recorded at New Takoradi whereas the highest concentrations of As (4.43 mg/kg) and Hg (0.027 mg/kg) were recorded at Shama. On the other hand, the highest concentration of Se (0.22 mg/kg) was found at Atuabo and Lower Axim, respectively, while the highest Zn concentration (57.51 mg/kg) was recorded at Dixcove. Generally, the mean metal concentration increased in the order of Hg<Se<As<Cu<Pb<Zn. The ANOVA revealed that there were significant difference ($p<0.05$) in the concentration of As and Se among the communities examined with the exception of Cu, Pb, Zn, and Hg which showed no significant difference ($p>0.05$). However, Cd was not found in any of the soil samples.

The concentration of arsenic in the soil samples anaylsed were below the WHO/FAO (2001) permissible limit of 20 mg/kg. Antwi-Agyei et al. (2009) recorded high values of arsenic in soil which ranged from 84.53 to 1711 mg/kg and attributed the high values of arsenic to the presence of pyrites in the bedrock of the area. Similarly, the concentrations of copper recorded in soils were below the WHO/FAO (2001) permissible limit of 100 mg/kg. The values recorded were within the normal range of copper concentration required by plants for growth and development. The concentration of copper recorded in this study was lower than earlier reported values of 47.0 mg/kg reported by Fisseha et al. (2008) and 22.14 mg/kg around an oil depot at Jos in Nigeria (Babatunde et al. 2014). Additionally, the concentrations of lead in soils were below the WHO/FAO (2001) permissible limit of 50 mg/kg. However, substantial amount of lead concentration was recorded at the study area indicating some anthropogenic source of lead pollution in the environment. The values recorded in this study were higher than of 14.13 mg/ kg and 13.53 mg/kg recorded in a previous study (Babatunde et al. 2014).

The zinc content of soils analyzed was below the WHO/FAO (2001) permissible limit of 300 mg/kg . However, the values of zinc recorded in this study were within the normal range of zinc required by plants. The concentration of zinc observed in this study was lower than 237.96 mg/kg reported in an earlier study (Okunola et al. 2007). A similar study conducted showed that zinc concentration in an industrial area was 49.7 mg/kg and 32.20 mg/kg in a rural area (Srinivas et al. 2009). The concentration of mercury recorded at the study area fell below the WHO/FAO (2001) permissible limit of 2.00 mg/kg. The mean value of mercury (0.141 mg/kg) recorded in soils (Kpan et al. 2014) was higher than those detected in this study. Mercury is an environmental pollutant which induces severe alteration in the body tissue and causes a wide range of adverse health effects. The mean concentrations of selenium recorded study area were below the WHO/FAO (2001) recommended limit of 10 mg/kg in soils. A study reported similar values in soils at the of selenium in soils as found in our work, which ranged from 0.022 to 3.806 mg/kg Jian'an Tan et al. (2002).

Heavy metal concentration in plant samples

Table 2 shows the mean concentration of heavy metals in plant samples analyzed at various communities. The mean concentrations of examined heavy metals were 2.7 mg/kg for As, 17.47 mg/kg for Cd, 3.17 mg/kg for Cu, 91.74 mg/kg for Pb, 1.51 mg/kg for Se, and 9.88 mg/kg for Zn. ANOVA revealed that there were significant difference ($p<0.05$) in the concentration of Cd, Pb, Se, and Zn among the communities except As and Cu which showed no significant difference ($p>0.05$). From the WHO/FAO guidelines the acceptable concentration of arsenic in plants is 0.15 mg/kg (WHO/FAO 2007). The mean concentration of arsenic was above the permissible limit of arsenic in plant samples. High concentration of arsenic in plants can cause nausea, vomiting, diarrhea, cough, headache and cardiovascular disease to animals especially livestock (ATSDR 2007a; Tchounwou et al. 2012).

The concentration of cadmium in plant samples were above the WHO/FAO limit of 0.20 mg/kg (WHO/FAO 2007). The concentration of cadmium reported in this study was higher than those reported by Nazir et al. (2015). The high concentration of cadmium could be as a result of domestic effluents or atmospheric deposition emanating from industrial activities from the surrounding areas. High levels of cadmium cause both acute and chronic poisoning, adverse effect on kidney, liver, vascular and immune system and gastrointestinal and reproductive effects (Maobe et al. 2012). The normal copper content in plant ranges from 2-20 mg/kg and WHO/FAO recommended guideline value of copper is 40 mg/kg (WHO/FAO 2007; Taber 2009). The concentration of copper recorded in this study fell within the range of copper required by plants for growth and development.

The concentration of lead in plant samples exceeded the WHO/FAO (2007) permissible limit of 5 mg/kg by over 17-fold. The consumption of high amount of lead can cause anaemia, headache, brain damage, and nervous system disorder to humans and animals (ATSDR 2007b; Shi et al. 2011). The permissible limit of zinc recommended by WHO/FAO (2007) is 60 mg/kg, however the mean of zinc concentration recorded were below the limit. Zinc is one of the essential trace elements which plays a vital role in physiological and metabolic processes of many living organism but can be harmful when it reaches higher concentration (Tchounwou et al. 2012).

TABLE 1
Concentration of heavy metals (mg/kg) in soil samples

Site	As	Cu	Hg	Pb	Se	Zn
Atuabo	1.00±0.36	4.59±3.46	0.01±0.00	20.10±5.23	0.22±0.01	48.65±21.13
Half Assini	1.29±0.71	0.86±0.57	ND	18.98±11.15	0.19±0.02	26.39±6.18
Lower Axim	3.03±0.71	12.10±1.74	0.01±0.00	24.25±2.70	0.22±0.012	54.29±8.95
Dixcove	1.64±0.88	1.64±1.55	0.01±0.00	16.14±2.59	0.20±0.003	57.51±20.65
Shama	4.43±3.01	6.89±3.34	0.03±0.01	21.80±7.58	0.18±0.09	21.80±7.58
Takoradia	0.97±0.62	13.20±4.49	ND	28.28±19.60	0.05±0.04	28.28±19.60
Mean±SD	2.06±1.27	6.55±4.75	0.02±0.01	21.59±3.88	0.18±0.06	39.49±14.36

ND: Too low to determine; a, New Takoradi

The concentration range of selenium of plant is about 0.05 to 1.0 mg kg-1 dry weight (Terry et al. 2000). The concentrations of selenium in the plant samples analyzed were higher than the recommended limit.

Relationship between the concentrations of heavy metals analyzed in the soils

Pearson's product moment of correlation coefficient was used to determine the association or relationship between the concentrations of heavy metals in soils (Table 3). For correlation significance, the criteria value of probabilities ($p<0.05$ and $p<0.01$) was used. Strong positive correlation was established between Hg/As and Pb/Cu which suggests that when one metal concentration increases the other also increases. Additionally strong negative correlation was established between Se/Hg and Zn/Hg suggests that when one metal concentration increases the other decreased. Moderate correlation was established between Se/Cu, Se/Pb, and Zn/Se (Table 3).

Assessment of metal contamination status

The EF values for the metals in the soils are presented in Table 4. Enrichment factor is a useful tool in evaluating the degree of anthropogenic metal contamination. Selenium was the heaviest contaminating element. The EF value for Se ranged from 12.45 to 50.57 with an average of 40.52. The highest EF value of Se was observed at Lower Axim. On the other hand, mean EF values of Cu, Hg, Zn and Pb were less than 2 indicating minimal enrichment of Cu, Hg, Zn and Pb. The mean EF value of As was observed in the range of 5-20 indicating significant enrichment. The extremely high EF value of Se suggests that a

TABLE 2
Concentration of heavy metals (mg/kg) in plant samples

Site	As	Cu	Hg	Pb	Se	Zn
Atuabo	3.41±2.63	18.37±2.47	2.80±1.68	87.3±5.09	1.51±0.08	9.08±0.89
Half Assini	3.71±3.38	17.8±1.09	2.59±0.77	87.27±4.87	1.56±0.06	9.51±3.18
Lower Axim	1.65±0.56	16.65±2.10	4.03±1.41	85.56±8.63	1.50±0.13	9.75±1.52
Dixcove	1.58±1.27	16.89±1.18	3.30±2.26	100.91±7.4	1.42±0.08	10.89±1.38
Shama	1.68±0.70	19.06±1.07	2.49±0.73	92.35±4.01	1.54±0.09	10.80±0.95
Takoradi	4.19±3.58	16.04±2.15	3.79±1.28	97.02±6.16	1.54±0.04	9.22±1.11
Mean+SD	2.70+1.2	17.47+1.14	3.17+0.64	91.74+6.17	1.51+0.05	9.88+0.79

TABLE 3
Pearson's product moment correlation coefficient between heavy metals content in soil

Element	As	Cu	Hg	Pb	Se	Zn
As	1.000					
Cu	0.187	1.000				
Hg	**0.809**[a]	0.012	1.000			
Pb	0.059	**0.946**[b]	0.149	1.000		
Se	0.255	-0.559	-0.921	-0.698	1.000	
Zn	-0.206	-0.085	-0.957a	-0.343	0.515	1.000

[a]Correlation is significant at the 0.05 level (2-tailed), [b]Correlation is significant at the 0.01 level (2-tailed)

significant amount of it has being introduced by anthropogenic sources such as fishing activities and domestic effluents. At Atuabo, Half Assini, Dixcove and New Takoradi, the EF values of As were in the range of 2-5 indicating moderate enrichment, while Lower Axim and Shama recorded EF values in the range of 5-20 showing significant enrichment. With regards to the EF values of Se, Atuabo, Half-Assini, Lower Axim, Dixcove and Shama were greater than 40, signifying extremely high enrichment of the metal. However, soil samples from New Takoradi showed lower yet significant EF values of Se. The mean EF values increased in the order of Cu<Zn<Hg<Pb<As<Se.

The I_{geo} values are shown on Table 5. With regards to the I_{geo} values, Se was the highest contaminants among the six selected metals studied. The I_{geo} values of As, Cu, Hg, Pb, and Zn were below 1, indicating that the study area was unpolluted with As, Cu, Hg, Pb and Zn. On the other hand, Se was found in the range of 1-2, indicating moderate pollution of Se at the study area. Based on the I_{geo} values, Atuabo, Half Assini, Lower Axim and Shama were within the range of 1-2 showing moderate pollution of Pb at the study area. The mean I_{geo} of the metals increased in the order of Cu<Hg<Pb<Zn<As<Se.

The pollution load index provides valuable information and advice for policy and decision makers to evaluate the pollution status of an area. The CF and PLI values for the six metals are presented in Table 6. Based on the CF values calculated, Se was the heaviest contaminant among the six metals studied. The CF values of Se ranged from 1.09 to 4.44 with an average of 3.55 indicating considerable contamination of Se in the soils of the study area. The CF values of As in the soil ranged from 0.54 to 2.46 with a mean value of 1.14 showing moderate contamination of As in the soils examined. Similarly, the CF values of Pb range from 1.29 to 2.26 with a mean value of 1.73 indicating moderate contamination of Pb in the soils studied. However, Atuabo, Half Assini, Lower Axim, Dixcove, and Shama recorded CF values in the range of 3-6 indicating that these sites were considerably contaminated with Se. The mean values of CF of metals increased in the order of

TABLE 4
Enrichment factor of heavy metals for soil samples

Sites	As	Cu	Hg	Pb	Se	Zn
Atuabo	2.55	0.012	1.61	1.06	49.20	0.082
Half Assini	3.27	0.002	-	0.99	45.05	0.044
Lower Axim	7.69	0.033	1.57	1.28	50.57	0.091
Dixcove	4.16	0.005	1.76	0.85	45.46	0.096
Shama	11.24	0.019	0.34	1.15	40.36	0.046
Takoradi	2.47	0.036	-	1.49	12.45	0.060
Min	2.47	0.002	-	0.85	12.45	0.044
Max	11.24	0.036	1.76	1.49	50.57	0.097
Mean	5.23	0.018	0.88	1.14	40.52	0.070

TABLE 5
Geoaccumulation indices of metals for soil samples

Sites	As	Cu	Hg	Pb	Se	Zn
Atuabo	-1.55	-4.54	-2.22	-2.45	1.52	-1.31
Half Assini	-1.29	-6.88	-	-2.66	1.39	-2.03
Lower Axim	0.13	-4.90	-5.34	-2.12	1.56	-0.97
Dixcove	-0.97	-7.09	-4.95	-2.72	1.41	-1.01
Shama	0.22	-4.15	-6.09	-2.35	0.94	-2.14
Takoradi	-1.76	-2.72	-	-2.18	-0.31	-1.88
Min	-1.76	-7.09	-6.09	-2.72	-0.31	-2.14
Max	0.22	-2.72	0	-2.12	1.56	-0.97
Mean	-0.87	-5.05	-3.10	-2.41	1.09	-1.56

TABLE 6
Contamination factor and pollution load index of heavy metals for soil samples

Site	As	Cu	Hg	Pb	Se	Zn	PLI
Atuabo	0.56	0.08	0.016	1.61	4.32	0.70	0.001
Half Assini	0.71	0.02	-	1.52	3.95	0.38	0.005
Lower Axim	1.68	0.22	0.015	1.94	4.44	0.78	0.006
Dixcove	0.901	0.03	0.017	1.29	3.99	0.82	0.0003
Shama	2.46	0.13	0.003	1.74	3.54	0.89	0.0004
Takoradi	0.54	0.24	-	2.26	1.09	0.51	0.038
Min	0.54	0.02	-	1.29	1.09	0.38	0.0003
Max	2.46	0.24	0.017	2.26	4.44	0.82	0.0380
Mean	1.14	0.12	0.009	1.73	3.55	0.60	0.008

Hg<Cu<Zn<As<Pb<Se.

The PLI obtained was in the range 0.0003 to 0.038 (Table 6). When the PLI is greater than 1, it implies that contamination exists. However, if the PLI value is less than 1, then there is no metal contamination. The PLI value recorded at all sampling sites was below 1, indicated no metal contamination. The lowest value (0.0003) of PLI was recorded at Dixcove whiles the highest value (0.038) of PLI was recorded at New Takoradi.

Conclusions

The spatial distribution of heavy metals (As, Cu, Hg, Pb, Se, and Zn) in soil samples collected from six communities in the western coast of Ghana has been studied in this work. The concentration of the metals in the soil samples analyzed were in ranges of 0.97-4.43 mg/kg for A-s, 0.86-13.20 mg/kg for Cu, 0.012-0.027 mg/kg for Hg, 16.14-28.28 mg/kg for Pb, 0.05-0.22 for Se and 21.80-57.51 for Zn. The mean concentrations of most of the heavy metals in the soil samples were within their natural corresponding background values. The mean EF values increased in the order of Cu<Zn<Hg<Pb<As<Se, while the mean Igeo of the metals increased in the order Cu<Hg<Pb<Zn<As<Se. Mean values of CF of metals increased in the order

Hg<Cu<Zn<As<Pb<Se. Our study has shown that metal loading coastal communities investigated is currently low with the exception of As, Pb and Se, which recorded considerable amount of pollution with respect to their background values in soils. Subsequent investigation should be conducted intermittently to monitor environmental pollution due to the on-going oil drilling activities and evaluate the public health risks associated with metal pollution. In view of our findings, remediation methods should be adopted by the Environmental Protection Agency and District authorities to safeguard the coastal communities.

Authors' contribution

BYF-M participated in the data collection and analysis and writing of the manuscript. MO contributed to data collection and writing of the manuscript. AO contributed sample preparation, data collection and analysis, laboratory experiments and prepared the first draft of the manuscript. EO-A contributed to data collection, sample preparation and laboratory experiments. IT contributed to data collection and manuscript writing. FKEN, DKA and AKN contributed to project design and manuscript writing. CG contributed to the data analysis and manuscript writing. GD contributed to data analysis while RAO contributed to the project design, data collection, manuscript writing, and coordination of the project.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgement

This research was funded by Office of Research, Innovation and Development, University of Ghana (URF/7/LMG-005/2013-2014). Special thanks go to staff of the Department of Clinical, Noguchi Memorial Institute of Medical Research and Ecological Laboratory, University of Ghana, in particular Messrs Prince Owusu and Emmanuel Ansah for their technical support. We are grateful to the Chief of Atuabo, District Chief Executives, Directors and Administrators of Shama, Secondi-Takoradi, Ahanta West, Nzema East, Ellembelle and Jomoro and helpers in these districts for the cooperation and support.

References

Acquah-Sam, E. (2014). Economic Effects of Oil and Gas Production and Management on the Ghanaian Economy. *European Scientific Journal*, 10(10), 463–479.

Agency for Toxic Substance and Disease Registry. (2007a). Toxicological Profile for Arsenic, U.S. Department of Health and Humans Services, Public Health Service, Centres for Diseases Control, Atlanta, GA. https://atsdr.cdc.gov/substances/toxsubstances.asp?toxid=3. Accessed 16 January 2017

Agency for Toxic Substance and Disease Registry. (2007b). Toxicological Profile for Lead, U.S. Department of Health and Humans Services, Public Health Service, Centres for Diseases…. Control, Atlanta, GA. https://atsdr.cdc.gov/substances/toxsubstances.asp?toxid=22. Accessed 16 January, 2017. Accessed 16 January 2017

Akoto, O., Ephraim, J. H., & Darko, G. (2008). Heavy Metals Pollution in Surface Soils in the Vicinity of Abundant Railway Servicing Workshop in Kumasi , Ghana. *International Journal of Environmental*

Research, 2(4), 359–364.

Antwi-Agyei, P., Hogarh, J. N., & Foli, G. (2009). Trace elements contamination of soils around gold mine tailings dams at Obuasi, Ghana. *African Journal of Environmental Science and Technology,* 3(11), 353–359.

Atiemo, M. (2011). Contamination assessment of heavy metals in road dust from selected roads in Accra, Ghana. *Research Journal of Environmental and Earth Sciences*, 3(5), 473–480.

Ato, A. F., Samuel, O., Oscar, Y. D., Alex, P., Moi, N., & Akoto, B. (2010). Mining and heavy metal polution: Assessment of aquatic environments in Tarkwa (Ghana) using multivariate statistical analysis. *Journal of Environmental Statistics*, 1, 1–13.

Ayensu, F. (2013). Managing Ghana's Oil Revenue: Ghana Petroleum Funds. *Asian Journal of Humanities and Social Sciences*, 1(2), 148–161.

Babatunde, O., Oyewale, A., & Steve, P. (2014). Bioavailable Trace Elements in Soils around Nnpc Oil Depot Jos, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology*, 8(1), 47–56.

Cevik, F., Göksu, M. Z. L., Derici, O. B., & Findik, O. (2009). An assessment of metal pollution in surface sediments of Seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. *Environmental Monitoring and Assessment*, 152(1-4), 309–317.

Chen, T-B., Zheng, Y-M., Lei, M., Huang, Z-C., Wu, H-T., Chen, H., et al. (2005). Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. *Chemosphere*, 60(4), 542–551.

Fisseha, I., Jorn, B., & Mats, O. (2008). The fate and bioavailability of some trace elements applied to two vegetable farms in Addis Ababa. *African Journal of Agricultural Research*, 3(11), 797–807.

Förstner, U., & Wittmann, G. T. W. (2012). *Metal Pollution in the Aquatic Environment.* Springer Science & Business Media.

Ghana Statistical Service. (2010). *Population and housing census: Summary report of final results*. Accra, Ghana.

Tan, J., Zhu, W., Wang, W., Li, R., Hou, S., Dacheng, W., et al. (2002). Selenium in soil and endemic diseases in China. *The Science of the Total Environment*, 284, 227–235.

Kirpichtchikova, T. A., Manceau, A., Spadini, L., Panfili, F., Marcus, M. A., & Jacquet, T. (2006). Speciation and solubility of heavy metals in contaminated soil using X-ray microfluorescence, EXAFS spectroscopy, chemical extraction, and thermodynamic modeling. *Geochimica et Cosmochimica Acta,* 70(9), 2163–2190.

Kpan, J. D. A., Opoku, B. K., & Gloria, A. (2014). Heavy Metal Pollution in Soil and Water in Some Selected Towns in Dunkwa-on-Offin District in the Central Region of Ghana as a Result of Small Scale Gold Mining. *Journal of Agricultural Chemistry and Environment*, 3(2), 40–47.

Lu, X., Li, L. Y., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2009). Contamination assessment of mercury and arsenic in roadway dust from Baoji, China. *Atmospheric Environment*, 43(15), 2489–2496.

Lu, X., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2009). Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. *Journal of Hazardous Materials,* 161(2-3), 1058–1062.

Maobe, M. A. G., Gatebe, E., Gitu, L., & Rotich, H. (2012). Profile of Heavy Metals in Selected Medicinal Plants Used for the Treatment of Diabetes , Malaria and Pneumonia in Kisii Region , Southwest Kenya. *Global Journal of Pharmacology,* 6(3), 245–251.

Muller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. *Geological Journal*, 2, 108–118.

Nazir, R., Khan, M., Masab, M., Rehman, H.U.R., & Rauf, N.U.R. (2015). Accumulation of Heavy Metals (Ni , Cu , Cd , Cr , Pb , Zn , Fe) in the soil , water and plants and analysis of physico-chemical parameters of soil and water Collected from Tanda Dam kohat . *Journal of Pharmacological, Science and Research*, 7(3), 89–97.

Okunola, O. J., Uzairu, A., & Ndukwe, G. (2007). Levels of trace metals in soil and vegetation along major and minor roads in metropolitan city of kaduna, Nigeria. *African. Journal of Biotechnology,* 6(14), 1703–1709.

Pakade, V. E., Cukrowska, E. M., Darkwa, J., Darko, G., Torto, N., & Chimuka, L. (2012). Simple and efficient ion imprinted polymer for recovery of uranium from environmental samples. *Water Science and Technology*, 65(4), 728–736.

Ra, K., Kim, E., Kim, K., Kim, J., Lee, J., & Choi, J. (2013). Assessment of heavy metal contamination and its ecological risk in the surface sediments along the coast of Korea. *Journal of Coastal Research*, 65, 105–110.

Shi, G., Chen, Z., Bi, C., Wang, L., Teng, J., Li, Y., et al. (2011). A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. *Atmospheric Environment*, 45(3), 764–771.

Taber, H. G. (2009). Plant Analysis Sampling Procedures and Micronutrient Characteristics with Emphasis on Vegetable Crops. Commercial Vegetable, Horticulture. Iowa State University.

Tchounwou, P. B., Patlolla, A. K., & Centeno, J. A. (2003). Carcinogenic and systemic health effects associated with arsenic exposure-a critical review. *Toxicologic Pathology*, 31(6), 575–588.

T**erry, N., Zayed, A. M., de Souza, M. P., & Tarun, A. S.** (2000). Selenium in higher plants. *Annual Review of Plant Physiology and Plant Molecular Biology,* 51, 401–432.

WHO/FAO. (2001). Codex Alimentarius Commission. Food Additives and Contaminants. Joint FAO/WHO Food standards Programme, ALINORM 10/12A: 1-289.

WHO/FAO. (2007). Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty Eight Session of the Codex Committee on Food Hygiene. Houston, United States of America, ALINORM 07/30/13.

Yongming, H., Peixuan, D., Junji, C., & Posmentier, E. (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Science of The Total Environment*, 355(1-3), 176–186.