

### Evaluation of the Levels of Selected Heavy Metals in Mangrove Ecosystem and Roadside Topsoil in Ghana

David K. Essumang, Louis K. Boamponsem, Christian K. Adokoh, John K. Bentum, Christiana Owusu, Millicent E. Adu-Boakye, Joseph Afrifa

Trace metals were determined in the soil and water of four lagoons, two estuaries, and four heavy-traffic roads in Greater Accra along the Atlantic coast of Ghana. The results showed that water samples from all of the water bodies studied were polluted with mercury (Hg) and less polluted with arsenic (As), nickel (Ni), and cadmium (Cd). The pollution status of water samples was confirmed by contamination degree (CD) analysis, which yielded values of >1 of Hg and <1 of As, Ni, and Cd. Evaluation of the data from the soil sample was enhanced by the application of pollution quantification tools—the pollution load index (PLI) and the index of geoaccumulation (IGEO)—which showed that the mangrove swamp soil studied is progressively degrading with Hg, As, Ni, and Cd. It was also revealed that vehicular emissions were a potential source of lead (Pb), Ni, and manganese (Mn) in the roadside soils monitored. From the results of this study, it is clear that the mangroves are gradually degrading and that measures should be established to control release of these metals into the environment.

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Mangrove wetlands embody a combination of saline and freshwater ecosystems. Some birds and fish species rely heavily on mangroves for shelter and completion of their life cycle (Aksoy, Demirezen, and Duman, 2005).

Mangrove ecosystems, characterized by high fluctuations in chemical and physical properties, are often subjected to strong human impacts, such as industrial and domestic waste discharge, that modify their morphology and affect their quality (Cesar et al., 2007). Despite their significant capacity to maintain and purify water passing through them (Barbier, Acreman, and Knowler, 1997), pollution is one of the major challenges to the sustainability of coastal areas (Cao and Wong, 2007), especially mangroves and lagoons. Industrial and domestic wastes contribute heavy metals to the environment (Cao and Wong, 2007; Jiang, Kirkman, and Hua, 2001). Heavy metals are classified among the most dangerous groups of anthropogenic environmental pollutants because of their toxicity and persistence in the environment (Carreras, Wannaz, and Pignata, 2009; Nyarko et al., 2008). Heavy-metal pollution of the mangrove ecosystem may reduce species abundance and stress fisheries resources. It may also pose health risks to people who consume food from such areas (Cao and Wong, 2007). In Africa, over the last decade, increases in both industrial activities and urbanization have led to a huge increase in wastes, including heavy metals, in all parts of the continent [World Overpopulation Awareness (WOA), 2012].

Though heavy-metal pollution is common in Ghanaian river estuaries and coastal areas, most studies have so far focused on environmental media in urban and industrial areas only. There is the need to investigate the heavy-metal pollution status of mangrove areas because, in Ghana, mangrove forest covers the greater part of lagoons, especially Accra's Kpeshie Lagoon and Korle Lagoon. Pollution in the

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*Affiliation of authors:* David K. Essumang, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana. Louis K. Boamponsem, Laboratory Technology Department, University of Cape Coast, Cape Coast, Ghana. Christian K. Adokoh, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana; and Chemistry Department, University of Johannesburg, Auckland Park Campus, Johannesburg, South Africa. John K. Bentum, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana. Christiana Owusu, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana. Millicent E. Adu-Boakye, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana. Joseph Afrifa, Laboratory Technology Department, University of Cape Coast, Cape Coast, Ghana.

*Address correspondence to:* David K. Essumang, PhD, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana; (phone) +233208214443; (e-mail) kofiessumang@yahoo.com.

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coastal areas may come from runoff from nearby heavy-traffic roads, as well (Cao and Wong, 2007; Fu and Wu, 2006). This article, therefore, assesses the levels of the heavy metals mercury (Hg), arsenic (As), nickel (Ni), and cadmium (Cd) in four mangrove swamps—Korle, Chemu, Sakumono, and Kpeshie—in Ghana, as well as Ni, lead (Pb), and manganese (Mn) in roadside topsoils from four heavy-traffic roads in the Ghanaian capital city of Accra.

## Materials and Methods

### Sampling Sites

The sampling sites involve areas in Ghana where most industries are situated. The lagoons in this area are Chemu (latitude 5.633°, longitude 0.0167°) and Sakumono (latitude 5.617°, longitude -0.033°) Lagoons in Tema, and Korle (latitude 5.55°, longitude -0.2166667°) and Kpeshie (latitude 5.567°, longitude -0.133°) lagoons in Accra. Sakumono Lagoon is west of Tema in the Greater Accra region and covers about 1,364 ha. The site is contiguous to the rapidly growing municipalities of Accra and Tema. It is the most urbanized wetland, with a large human population in its immediate vicinity. The Kpeshie drainage basin, which covers a relatively small catchment area (110 km<sup>2</sup>), is bounded on the east by the Ghana Military Academy at Teshie and on the north by a line south of Madina and Ajirignano. It covers the eastern part of Accra: Ridge, Cantonments, Osu, Labadi, and Burma camp areas. Streams in the catchment

generally flow north to south, emptying directly into the principal outlet to the sea at Kpeshie Lagoon or the small Korle Lagoon at Osu (Figure 1).

Korle Lagoon, which covers 250 km<sup>2</sup>, is bounded on the west by a line running roughly south to north from Gbebe in Dansoman, whereas the Chemu catchment also covers about 250 km<sup>2</sup> bounded by Kwashieman and New Achimota; on the north by the Achimota–Legon axis; and on the east by East Legon, the Accra Airport, and Ridge. The highest spot on the basin is about 308 m above sea level. The principal streams that drain the catchment are the Odaw River and its tributaries: the Nima, the Onyasia, the Dakobi, and the Ado. The principal outlet for water in this catchment is the Korle Lagoon. On the other hand, four major roads (i.e., heavy-traffic roads) in Accra and its surrounding area were also studied for their heavy-metal deposits on the roadside. The roads are Obasanjo–CSIR Road [sampling points (SPs) 1–5], Legon–Atomic Road (SPs 6–10), Madina–Adenta Road (SPs 11–15), and Burma camp–Circle Road (SPs 16–20).

### Sample Collection and Analyses

Soil and water samples were collected monthly from the designated sampling points of the four mangrove sites from December 2008 through June 2009. Roadside topsoils were also collected during the same period from the four major roads in Accra [Obasanjo–CSIR, Legon–Atomic, Madina–Adenta (SPs 16–20), and Burma camp–Circle].

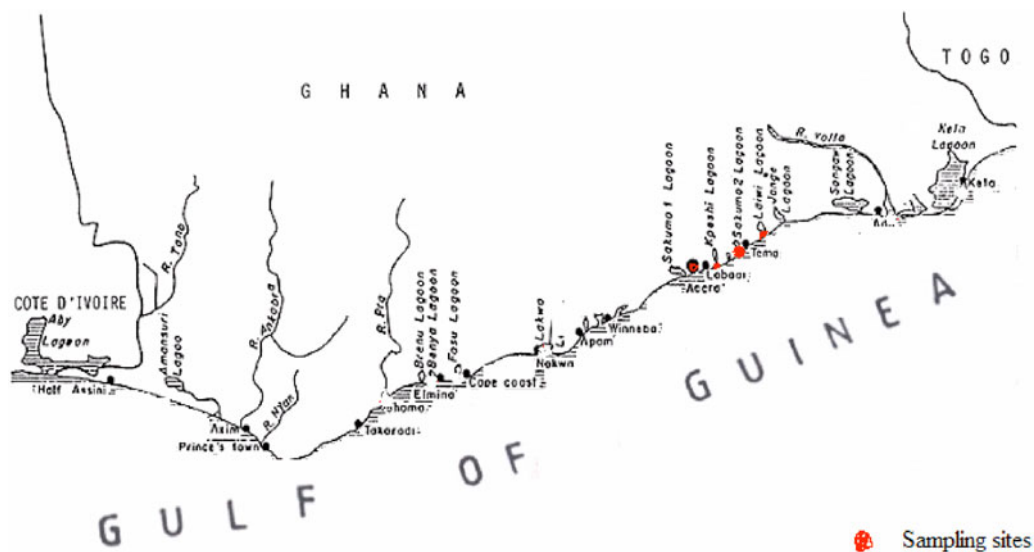


Figure 1. Map of the sampling sites.

Soil samples from the mangroves were collected at a depth of about 10–20 cm following the method of Teng et al. (2004). In all, 36 soil samples were thus collected, with three samples taken from each site, with the following sample codes: Korle (SP1–SP3), Chemu (SP4–SP6), Sakumono (SP7–SP9), and Kpeshie (SP10–SP12). Soil samples from the selected roads were collected at a distance of 3 m from the edges on both sides and 50 m between consecutive sampling points on each road. In all, 48 samples were collected from the roads over the study period. The soil samples were packed in polyethylene bags rinsed previously with 1 M hydrogen chloride and transported to the laboratory. In the lab, the samples were disaggregated; dried in a dry, dust-free place at room temperature for 3 days; homogenized; sifted through 212- $\mu$ m sieves; packed in polyethylene bags; and stored in a dry, dust-free cardboard for the assay of metals, which was performed within five days of sampling.

Two replicates (1 g each) of the homogenized soil samples from each sampling site were acid-digested following United States Environmental Protection Agency (USEPA) 1996 guidelines. Also acid digested in a similar manner as the soil samples was 10 ml distilled water to serve as a blank. The digested soil samples and the blank were analyzed for Hg, As, Ni, Cd, Pb, and Mn by using an atomic absorption spectrophotometer (AAS) (Analyst 400; PerkinElmer Vernon Hills, IL). All chemicals used were of analytical grade (Sigma Aldrich, Munich).

A total of 12 water samples (two samples each from four lagoons and two estuaries) were carefully collected from the four mangrove lagoons—Kpeshie, Chemu, Sakumono, and Korle—and from the Kpeshie and Korle estuaries. In all, 36 samples were used for water analysis.

Precleaned, 1-liter polyethylene sampling bottles were used for the collection of water samples. At each sampling point, the bottles were rinsed three times with the water before collection of the sample. Water samples were collected from about 8 cm below the water surface. pH, temperature, salinity, and conductivity parameters were determined immediately on site, after which samples were acidified with 50% nitric acid to achieve a pH of 2.0 (Serfor-Armah et al., 2006), transported in an ice chest to the laboratory, and stored in a refrigerator for further analyses. The pH, conductivity, and salinity of the water samples were analyzed by both classic and automated instrumental methods prescribed by the standard methods for the analysis of water (American Public Health Association, 1995, pp. 2–56) and USEPA (1983) guidelines by using a benchtop pH meter (AZ86555; Eztech Instruments, Brunswick, NJ) and Abbe

refractometer AR2008 (A. Krüss Optronics, Hamburg). Before acid digestion, water samples were filtered and were treated in a similar manner as the blank solution, and a composite of two samples from each sampling site was used to determine heavy metals. Then, 10 ml of each water sample was also acid digested in a similar manner as the soil samples following USEPA 1996 guidelines within two days.

The accuracy and precision of the analytical method were verified by using 2 ppm silver (Ag 39361, lot 1365599), aluminum (Al 39435, lot 1404169), arsenic (As 39436, lot 1406015), barium (Ba 90092, lot 1378904), nickel (Ni 42242, lot 1402879), mercury (Hg 16482, lot 1420021), and cobalt (Co 05202, lot 1395579) solutions purchased from Sigma Aldrich (Fluka; St. Louis, MO), which were prepared from Cal-1 stock solution. The measured values compared favorably well with the prepared standard, with a bias of >6%. The precision, which was calculated as percentage relative standard deviation (%RSD) of six replicate samples of the prepared standard, was found to be >5%. In fact, the reference material was the only one available during the time of analysis and was used to establish the reliability of the digestion process, as well as the efficiency of the AAS instrument.

## Quantification of Soil Contamination

The degree of metal contamination in the soil samples was quantified by using the index of geoaccumulation (IGEO) (Boamponsem, 2009; Bhuiyan et al., 2010; Förstner et al., 1990; González-Macias et al., 2006; Grzebisz et al., 2002; Karbassi et al., 2008; Lokeshwari and Chandrappa, 2007; Teng et al., 2004; Yaqin et al., 2008) and pollution load index (PLI) (Adomako et al., 2008; Boamponsem et al., 2010; Tomlinson et al., 1980). For water samples, the degree of metal contamination was also quantified by contamination degree (CD) (Müller, 1979; Teng et al., 2004).

## Data Analyses

The pollution indices were computed by using Microsoft Excel 2007. Mean concentrations, standard deviations, and graph plots were estimated by using SPSS version 16 software.

# Results and Discussion

## Mangrove Water Quality

The results of the analyses of the physicochemical properties of the mangrove swamp water and metal concentra-

**Table 1.** Physicochemical properties of mangrove swamp water samples

Sampling site	pH	Temperature °C	Conductivity ( $\mu\text{S cm}^{-1}$ )	Salinity (ppt)
Korle Lagoon	7.01	25.80	5,170	1.12
Korle estuary	7.61	25.20	49,400	4.20
Chemu Lagoon	6.92	26.10	2,210	0.42
Sakumono Lagoon	6.84	25.85	2,747	0.65
Kpeshie Lagoon	7.65	25.50	2,460	0.80
Kpeshie estuary	7.62	25.30	36,100	4.18
Mean	7.28	25.63	16,347.83	1.90
SD	0.39	0.35	20,905.84	1.80

tions are listed in Tables 1 and 2, respectively. The pH and temperature of the water samples from the four sites were within the general values for brackish water (6.5–8.5 and 22°–29°C, respectively). However, the conductivity of water at all the sampling points was very high. The highest conductivity [49,400 micro-Siemens ( $\mu\text{S}$ )  $\text{cm}^{-1}$ ] was recorded for water samples from Korle Lagoon, whereas Chemu Lagoon registered the lowest level (2,210  $\mu\text{S cm}^{-1}$ ). Conductivity has generally been used in the field as a first screen for water quality; high conductivity is often the result of any activity that increases total dissolved solids (National Mining Association, 2010). Conductivity of water may be affected by the presence of inorganic dissolved solids such as chloride, sulfate, sodium, and calcium. In addition, elevated conductivity may be related to the geology of the area through which the water flows, as well as industrial or urban runoff (including that from nearby roadsides) (Colorado River Watch Network, 2010). Mangrove grows usually at the intertidal coastal zones with regular flushing from saline water, which may be a reason for the high conductivity.

The variation in salinity levels (0.45–4.2 ppt) in the study area indicates occasional saltwater intrusion. The mangrove

swamps studied can be regarded as brackish water zones with intermittent contact with the marine environment.

The amounts of the metals monitored in the water samples (Table 2) were below the World Health Organization (WHO) (2004), Ghana EPA (1997), and World Bank (1995) maximum allowable thresholds, except for Hg, which exceeded the WHO maximum allowable limit (0.001  $\mu\text{g liter}^{-1}$ ). This indicates that there is a high anthropogenic influx of Hg, and that of As, Ni, and Cd is in close vicinity of the mangrove swamps studied. According to Boadi and Kuitunen (2002), industrial, domestic, and hospital wastes discharged into Korle Lagoon, especially, and other water bodies under study, have further degraded the water quality upstream. Sediments in these lagoons trap effluents from upstream. According to Laing (1994), a survey of manufacturing industries in the Greater Accra region showed that the metal industry creates 16% of the total industrial waste and, as the population has increased and in the era of industrialization, the percentage might have increased recently, which may account for high level of Hg recorded.

On the contrary, the concentrations of the metals monitored were relatively high in the sediment samples from the mangrove swamps (Table 3). All soil samples from Korle, Sakumono, and Kpeshie registered Hg concentrations above the WHO (2004) recommended value of 0.001  $\mu\text{g g}^{-1}$ . The Hg levels at all the sampling points, except SP5 and SP6 (Chemu), were above the limit of 0.002  $\mu\text{g g}^{-1}$  for heavily polluted water requiring investigation and cleanup reported by VROM (Bodemsanering, 1983). Except for soil samples from sampling points at Chemu and for SP12 at Kpeshie, the sampling points registered Hg concentrations above the geochemical world average shale value of 0.4  $\mu\text{g g}^{-1}$  reported by Turekian and Wedepohl (1961) but less than the effect range median (ERM) sediment-quality guidelines (0.71  $\mu\text{g g}^{-1}$ ) that represent the chemical level above which aquatic organisms are frequently affected (Long et al., 1995).

**Table 2.** Mean ( $\pm$ SD) metal concentration ( $\mu\text{g liter}^{-1}$ ) of mangrove swamp water samples ( $n = 18$ )

Sampling site	Hg	As	Ni	Cd
Korle Lagoon	0.0024 $\pm$ 0.001	0.0197 $\pm$ 0.008	0.0062 $\pm$ 0.001	0.00015 $\pm$ 0.0001
Korle estuary	0.0059 $\pm$ 0.001	0.0032 $\pm$ 0.002	0.0045 $\pm$ 0.003	0.00003 $\pm$ 0.0001
Chemu Lagoon	0.0034 $\pm$ 0.001	0.0088 $\pm$ 0.001	0.0092 $\pm$ 0.001	0.00025 $\pm$ 0.0001
Sakumono Lagoon	0.0090 $\pm$ 0.002	0.0021 $\pm$ 0.001	0.0063 $\pm$ 0.001	0.00063 $\pm$ 0.0001
Kpeshie Lagoon	0.0048 $\pm$ 0.001	0.0117 $\pm$ 0.001	0.0055 $\pm$ 0.002	0.00079 $\pm$ 0.0001
Kpeshie estuary	0.0062 $\pm$ 0.001	0.0197 $\pm$ 0.001	0.0047 $\pm$ 0.001	0.00052 $\pm$ 0.0001
Blank	<0.001	<0.006	<0.005	<0.001

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

**Table 3.** Mean ( $\pm$ SD) metal concentration ( $\mu\text{g g}^{-1}$ ) of roadside topsoil soil samples

Sampling site	Sampling point	Hg	As	Ni	Cd
Korle	SP1	1.003 $\pm$ 0.033	25.85 $\pm$ 10.85	12.125 $\pm$ 2.19	0.853 $\pm$ 0.03
	SP2	0.438 $\pm$ 0.014	10.20 $\pm$ 4.28	7.945 $\pm$ 1.44	0.805 $\pm$ 0.028
	SP3	0.433 $\pm$ 0.014	3.663 $\pm$ 1.54	8.885 $\pm$ 1.60	0.793 $\pm$ 0.027
Chemu	SP4	0.393 $\pm$ 0.001	6.933 $\pm$ 0.25	<0.0055	0.318 $\pm$ 0.11
	SP5	<0.009	7.122 $\pm$ 0.257	<0.0055	0.295 $\pm$ 0.102
	SP6	<0.009	42.11 $\pm$ 1.52	<0.0055	0.778 $\pm$ 0.27
Sakumono	SP7	1.248 $\pm$ 0.400	49.36 $\pm$ 24.12	0.796 $\pm$ 0.039	0.67 $\pm$ 0.15
	SP8	0.655 $\pm$ 0.210	8.393 $\pm$ 4.10	0.006 $\pm$ 0.011	0.72 $\pm$ 0.161
	SP9	0.485 $\pm$ 0.155	6.835 $\pm$ 3.34	6.52 $\pm$ 0.412	0.099 $\pm$ 0.012
Kpeshie	SP10	1.24 $\pm$ 0.670	2.62 $\pm$ 1.06	21.01 $\pm$ 9.76	0.363 $\pm$ 0.041
	SP11	1.588 $\pm$ 0.858	13.155 $\pm$ 5.34	2.708 $\pm$ 1.26	0.445 $\pm$ 0.05
	SP12	0.29 $\pm$ 0.157	6.37 $\pm$ 2.59	27.76 $\pm$ 12.9	0.457 $\pm$ 0.051

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

Soil samples from four sampling points (SP1, SP6, SP7, and SP11) had As concentrations above the world average shale concentration of 13  $\mu\text{g g}^{-1}$ . However, the As concentration in the soil samples from all the sampling points, except SP6 and SP7, were within the normal soil As concentration range of 0.1–40  $\mu\text{g g}^{-1}$  reported by Bowen (1979) and less than the ERM sediment-quality guidelines (70  $\mu\text{g g}^{-1}$ ) that

represents the chemical level above which aquatic organisms are frequently affected (Long et al., 1995).

These results show the historical record of natural and anthropogenic fluxes of heavy metals drained into the water basin. Geochemical investigation of sediments provides information about the quality and quantity of heavy metals

**Table 4.** Mean ( $\pm$ SD) metal concentration ( $\mu\text{g g}^{-1}$ ) of roadside topsoil samples

Sampling site	Sampling point	Ni	Pb	Mn
Obasanjo–CSIR	SP1	3.30 $\pm$ 2.08	16.22 $\pm$ 10.78	17.44 $\pm$ 3.94
	SP2	2.59 $\pm$ 1.63	23.61 $\pm$ 15.69	19.42 $\pm$ 4.37
	SP3	2.87 $\pm$ 1.81	12.18 $\pm$ 8.10	16.73 $\pm$ 3.77
	SP4	6.68 $\pm$ 4.20	8.42 $\pm$ 5.60	16.47 $\pm$ 3.71
	SP5	2.10 $\pm$ 1.32	25.47 $\pm$ 16.93	14.97 $\pm$ 3.72
Legon–Atomic	SP6	2.15 $\pm$ 1.35	8.95 $\pm$ 5.95	16.68 $\pm$ 3.76
	SP7	3.05 $\pm$ 1.92	7.33 $\pm$ 4.87	15.55 $\pm$ 3.50
	SP8	1.66 $\pm$ 1.04	6.22 $\pm$ 4.14	16.37 $\pm$ 3.69
	SP9	2.56 $\pm$ 1.61	23.11 $\pm$ 15.36	21.52 $\pm$ 4.85
	SP10	9.18 $\pm$ 5.77	6.98 $\pm$ 4.64	30.89 $\pm$ 6.96
Madina–Adenta	SP11	1.52 $\pm$ 0.96	5.70 $\pm$ 3.79	16.79 $\pm$ 3.78
	SP12	1.66 $\pm$ 1.05	6.67 $\pm$ 4.43	14.95 $\pm$ 3.37
	SP13	3.16 $\pm$ 1.99	6.48 $\pm$ 4.31	17.71 $\pm$ 3.99
	SP14	2.62 $\pm$ 1.65	6.13 $\pm$ 4.07	16.00 $\pm$ 3.60
	SP15	1.33 $\pm$ 0.83	6.02 $\pm$ 4.00	13.27 $\pm$ 2.99
Burma camp–Circle	SP16	3.03 $\pm$ 1.91	5.44 $\pm$ 3.62	17.16 $\pm$ 3.87
	SP17	2.95 $\pm$ 1.85	5.87 $\pm$ 3.90	21.48 $\pm$ 4.84
	SP18	2.24 $\pm$ 1.41	6.25 $\pm$ 4.16	19.03 $\pm$ 4.29
	SP19	1.97 $\pm$ 1.24	5.05 $\pm$ 3.36	13.03 $\pm$ 2.94
	SP20	2.14 $\pm$ 1.34	7.04 $\pm$ 4.68	18.70 $\pm$ 4.21

Mn, manganese; Ni, nickel; Pb, lead.



adsorbed by the sediments (Das, 2005). The sediment of any water body may preserve a historical record of the natural and anthropogenic fluxes of heavy metals drained into the water basin (Sin et al., 2001). Soil samples from wetlands could provide a deeper insight into the long-term pollution state of the water body (Awofolu et al., 2005).

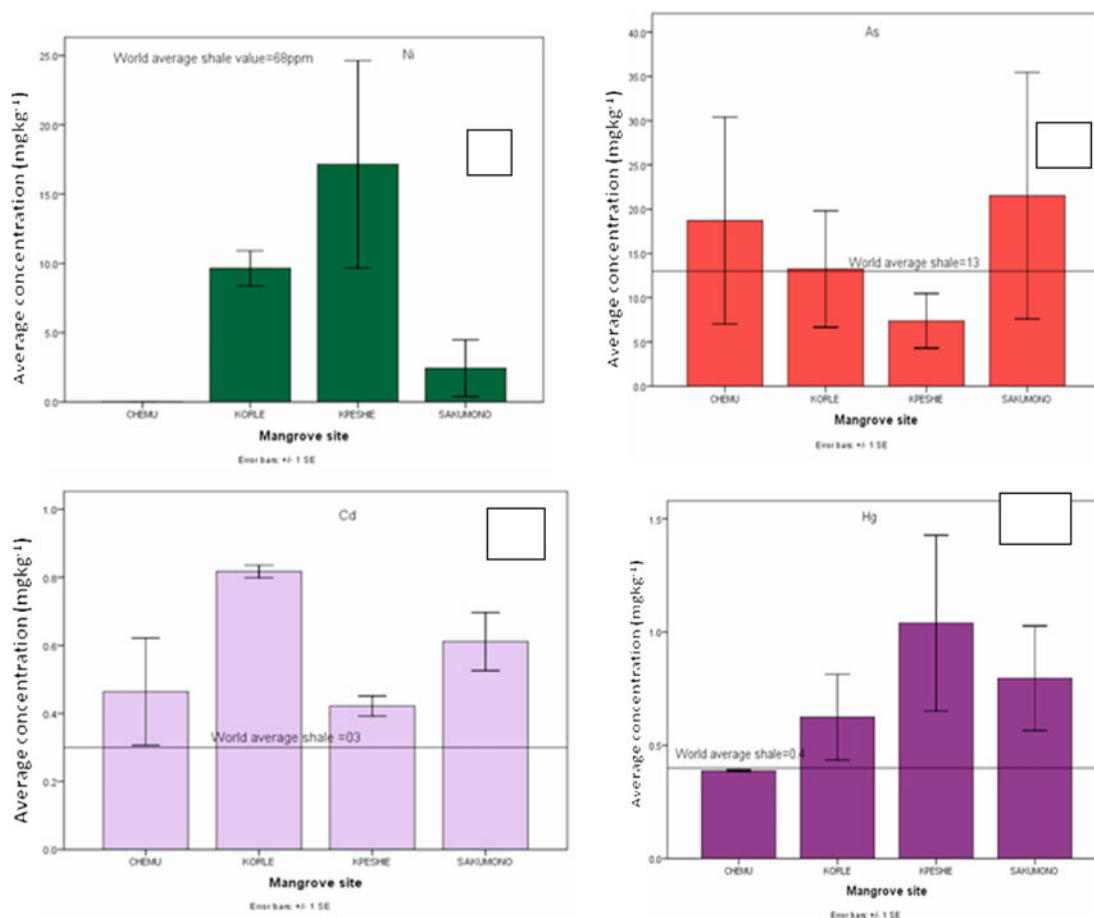
The range of Ni concentration in the soil samples from the mangrove sites was  $<0.0055$  to  $27.76 \mu\text{g g}^{-1}$ , which was lower than the world average shale value of  $68.0 \mu\text{g g}^{-1}$  reported by Turekian and Wedepohl (1961). The Cd concentration in all the soils, though higher than the world average shale level of  $0.3 \mu\text{g g}^{-1}$ , was within the normal soil range of  $0.01$ – $2.0 \mu\text{g g}^{-1}$  reported by Bowen (1979).

The mangrove wetland ecosystem is an important vegetative buffer from chemicals, including metals from anthropogenic activities (Lin and Dushoff, 2004). This means

that, to protect the aquatic environment, every effort should be made to stop the diminution of the mangroves. Figure 2 shows the variations in the concentration of the four metals in the mangrove swamp soils.

### Roadside Topsoils

Table 4 lists the concentrations of Ni, Pb, and Mn measured in roadside topsoils collected from 20 sampling points on 37 Obasanjo–CSIR, Legon–Atomic, Madina–Adenta, and Burma camp–Circle roads. These busy roads in Accra have drainage channeled to the mangrove ecosystem studied. The ranges recorded of Ni and Mn concentrations in the soil samples were from  $1.52 \pm 0.96$  to  $9.18 \pm 5.77 \mu\text{g g}^{-1}$  and from  $13.03 \pm 2.94$  to  $30.89 \pm 6.96 \mu\text{g g}^{-1}$ , respectively. As noted by Golow (1993), one source of metals in the Ghanaian environment is the heavy highway traffic.



**Figure 2.** Spatial distribution of metal concentrations in mangrove swamps: (A) nickel (Ni), (B) arsenic (As), (C) cadmium (Cd), and (D) mercury (Hg).

The Pb concentration in the roadside soil samples ranged between  $5.05 \pm 3.36 \mu\text{g g}^{-1}$  and  $25.47 \pm 16.93 \mu\text{g g}^{-1}$ . Soil samples from three roadside sampling points (SP2, SP5, and SP9) recorded Pb concentrations above the value of  $20 \mu\text{g g}^{-1}$  in world average shale reported by Turekian and Wedepohl (1961). This is not surprising, because these points are located at the high-density traffic area at the Burma camp–Circle Road in Accra. The main source of this metal is likely vehicular emissions, as observed by Howard and Sova (1993) and Al-Chalabi and Hawker (2000).

### Pollution Indices of Mangrove Swamp Soil and Roadside Topsoil Samples

Pollution indexing of metals provides a simple, comparative means for assessing site quality at a given time (Bhuiyan et al., 2010; Harikumar and Jisha, 2010). The contamination factors (CFs) of Hg, As, Ni, and Cd for each sampling point from the mangrove swamps are listed in Table 5. The results reveal that, except for Chemu, the sites are low to moderately contaminated with mercury ( $1 < \text{CF} < 4$ ). For AS, four sampling points (SP1, SP6, SP7, and SP11) registered CFs above the baseline value of 1. Except for SP5, the sampling points registered CFs above the baseline value for Cd. This implies that, on the pollution scale, these mangrove sites are medium to moderately contaminated with Cd. The results suggest that the wastewater from the various drainage systems (containing both industrial and household wastes) linking the mangrove swamps are a potential source of these metals. This result is not surprising, because the lagoons receive virtually all of the runoff from

**Table 5.** Contamination factor (CF) and pollution load index (PLI) of mangrove swamp soil samples

Sampling site	Sampling point	CF <sub>Hg</sub>	CF <sub>As</sub>	CF <sub>Ni</sub>	CF <sub>Cd</sub>	PLI
Korle	SP1	2.508	1.988	0.17	2.843	1.261
	SP2	1.095	0.784	0.117	2.683	0.720
	SP3	1.083	0.282	0.131	2.643	0.570
Chemu	SP4	0.983	0.533	—	1.060	0.822
	SP5	—	0.548	—	0.983	0.734
	SP6	—	3.239	—	2.593	2.898
Sakumono	SP7	3.120	3.797	0.012	2.233	0.746
	SP8	1.638	0.646	0.000	2.400	0.122
	SP9	1.213	0.526	0.096	1.477	0.548
Kpeshie	SP10	3.100	0.202	0.309	1.210	0.695
	SP11	3.970	1.012	0.040	1.483	0.698
	SP12	0.725	0.490	0.408	1.523	0.686

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

**Table 6.** Contamination degree of the lagoon and estuary water samples

Sample sites	Hg	As	Ni	Cd
Korle Lagoon	1.400	-0.606	-0.690	-0.950
Korle estuary	4.900	-0.936	-0.775	-0.990
Chemu Lagoon	2.400	-0.824	-0.540	-0.917
Sakumono Lagoon	8.000	-0.958	-0.685	-0.79
Kpeshie Lagoon	3.800	-0.766	-0.725	-0.737
Kpeshie estuary	5.200	-0.606	-0.765	-0.827

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

Accra. As a result, its polluted state was anticipated (Boadi and Kuitunen, 2002; Water Resource Associates, 1997).

Water-sample pollution was assessed by using CF, PLI, and CD. The CD index for Hg of all the water samples from the six sampling sites was  $<1$ , signifying consistent pollution by Hg in the water bodies. The CDs of As, Ni, and Cd were all  $>1$  and negative (Table 6), also showing less pollution by those metals in the water bodies. In the case of CF and PLI, the situation was different, as all the metals showed less pollution by registering CF values of  $>1.2$  (Nyarko et al., 2008) and 0–1 for PLI (Angulo, 1999; Ketoh, Sato, and Yamamoto, 2003) (Table 7). The reason is that CF and PLI provide simple but comparative means for assessing site quality, whereas CD measures the excessive values of elements monitored in the water samples (Teng et al., 2004).

Figure 3 depicts the PLI variations across the sampling points in the mangrove swamps. A PLI value of 1 indicates that only the baseline level of the metal is present, whereas values above 1 indicate progressive degradation of the site (Boamponsem et al., 2010; Harikumar and Jisha, 2010; Tomlinson et al., 1980). These results show that SP1 at Korle mangrove swamp is being progressively degraded by Hg, As, Ni, and Cd. They also reveal that SP6 at Chemu mangrove swamp is polluted with As and Cd.

The IGEO from this study shows that the mangrove ecosystem studied is practically unpolluted to moderately polluted by Hg, As, and Ni (Table 8). IGEOs for all of the sampling sites indicate that the mangrove ecosystem monitored is practically unpolluted by Cd (Table 8).

As shown in Table 9, the soil samples from all the sampling points from the various roads studied have contamination factors for Ni and Mn below the baseline value of 1. However, for Pb, three sampling points (SP2, SP5, and SP9) in

**Table 7.** Contamination factor (CF), pollution load index (PLI), and contamination degree of lagoons and estuaries

Sampling site	CF				PLI
	Hg	As	Ni	Cd	
Korle Lagoon	$6 \times 10^{-3}$	$1.52 \times 10^{-3}$	$9.12 \times 10^{-5}$	$5.00 \times 10^{-4}$	$8.03 \times 10^{-4}$
Korle estuary	0.015	$2.46 \times 10^{-4}$	$6.62 \times 10^{-5}$	$1.00 \times 10^{-3}$	$7.03 \times 10^{-4}$
Chemu Lagoon	$8.5 \times 10^{-3}$	$6.77 \times 10^{-4}$	$1.35 \times 10^{-4}$	$8.30 \times 10^{-4}$	$8.96 \times 10^{-4}$
Sakumono Lagoon	0.023	$1.62 \times 10^{-4}$	$9.25 \times 10^{-5}$	$2.10 \times 10^{-3}$	$9.22 \times 10^{-4}$
Kpeshie Lagoon	0.012	$9.0 \times 10^{-4}$	$8.09 \times 10^{-5}$	$2.36 \times 10^{-3}$	$7.81 \times 10^{-4}$
Kpeshie estuary	0.016	$1.52 \times 10^{-3}$	$6.91 \times 10^{-5}$	$1.73 \times 10^{-3}$	$1.31 \times 10^{-3}$

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

**Table 8.** Index of geoaccumulation (IGEO) of mangrove swamp soil samples

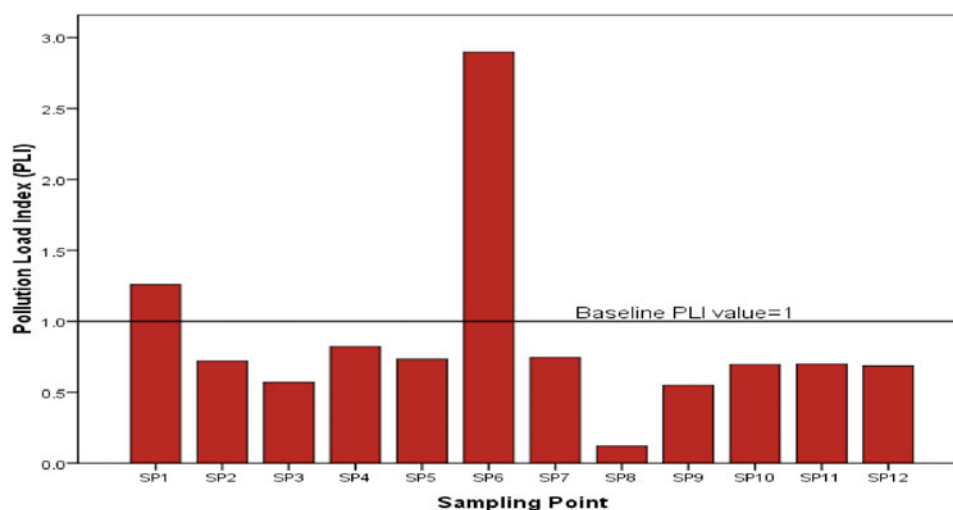
Sampling site	Sampling point	Hg	As	Ni	Cd
Korley	SP1	0.0072	0.2406	0.0353	-0.5097
	SP2	-1.9850	0.1718	0.0309	-0.6954
	SP3	-2.0126	0.0961	—	-0.7436
Chemu	SP4	-2.2457	0.1433	—	-3.6731
	SP5	—	0.1452	—	-3.9138
	SP6	—	0.2767	—	-0.8048
Sakumono	SP7	0.5327	0.2885	-0.0032	-1.2839
	SP8	-1.0174	0.1574	-0.0724	-1.0532
	SP9	-1.7399	0.1422	0.0265	-2.6103
Kpeshie	SP10	0.5172	0.0713	0.0431	-3.2488
	SP11	1.1120	0.1906	0.0141	-2.5958
	SP12	-2.9765	0.1370	0.0470	-2.5105

As, arsenic; Cd, cadmium; Hg, mercury; Ni, nickel.

heavy-traffic areas registered values above unity. This result agrees with the observations reported by Al-Chalabi and Hawker (2000), Ramakrishnaiah and Somashekar (2002), and Atayese et al. (2009). The pollution effect of Ni, Pb, and Mn on roadside topsoil is within baseline levels. The IGEO (Table 10) for the roadside topsoils also revealed that the sampling sites monitored are unpolluted to moderately polluted with Ni, Pb, and Mn.

## Conclusions

Some mangrove ecosystems in Ghana are being rapidly reclaimed to make room for development. The remaining mangrove swamps are also threatened by emerging industrial activities and intense human disturbances. When one



**Figure 3.** Variation of the pollution load index (PLI) across the sampling points of the mangrove ecosystem studied.



**Table 9.** Contamination factor (CF) and pollution load index (PLI) of roadside topsoil samples

Sampling site	Sampling point	CF <sub>Ni</sub>	CF <sub>Pb</sub>	CF <sub>Mn</sub>	PLI
Obasanjo–CSIR	SP1	0.049	0.811	0.021	0.093
	SP2	0.038	1.181	0.023	0.101
	SP3	0.042	0.609	0.020	0.080
	SP4	0.098	0.421	0.019	0.093
	SP5	0.031	1.274	0.018	0.088
Legon–Atomic	SP6	0.032	0.448	0.020	0.065
	SP7	0.045	0.367	0.018	0.067
	SP8	0.024	0.311	0.019	0.053
	SP9	0.038	1.156	0.025	0.103
	SP10	0.135	0.349	0.036	0.120
Madina–Adenta	SP11	0.022	0.285	0.020	0.050
	SP12	0.024	0.334	0.018	0.052
	SP13	0.046	0.324	0.021	0.068
	SP14	0.038	0.306	0.019	0.061
	SP15	0.019	0.301	0.016	0.045
Burma camp–Circle	SP16	0.045	0.272	0.020	0.063
	SP17	0.043	0.293	0.025	0.068
	SP18	0.033	0.313	0.022	0.061
	SP19	0.029	0.253	0.015	0.048
	SP20	0.031	0.352	0.022	0.062

Mn, manganese; Ni, nickel; Pb, lead.

considers the vital role mangrove wetlands play in the environment (such as serving as a vegetative buffer zone, preventing erosion, facilitating the biological degradation of chemicals, and providing shelter for ecologically important organisms), it is imperative to investigate the impact of human activities on the sustainability of this ecosystem.

The results of this study show that the mangrove ecosystem studied is threatened by anthropogenic activities, which are increasing along these areas. The results also suggest that vehicular emission is a source of Pb in the roadside soils.

It is envisioned that the results of this study will enrich the discussion and understanding of the effects of anthropogenic activities on the mangrove ecosystems. It is recommended that study of the bioavailability of metals to aquatic organisms involving metal speciation and that exposure modeling must be integrated in future studies on metal assessment of mangrove ecosystems in Ghana.

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**Table 10.** Index of geoaccumulation (IGEO) of roadside topsoils

Sampling site	Sampling point	IGEO <sub>Ni</sub>	IGEO <sub>Pb</sub>	IGEO <sub>Mn</sub>
Obasanjo–CSIR	SP1	0.0169	0.1340	0.0032
	SP2	0.0135	0.1521	0.0034
	SP3	0.0149	0.1202	0.0032
	SP4	0.0269	0.1025	0.0032
	SP5	0.0105	0.1557	0.0031
Legon–Atomic	SP6	0.0108	0.1054	0.0032
	SP7	0.0158	0.0958	0.0031
	SP8	0.0071	0.0879	0.0032
	SP9	0.0133	0.1510	0.0035
	SP10	0.0314	0.0934	0.0039
Madina–Adenta	SP11	0.0060	0.0837	0.0032
	SP12	0.0072	0.0913	0.0031
	SP13	0.0163	0.0899	0.0033
	SP14	0.0136	0.0872	0.0031
	SP15	0.0040	0.0863	0.0029
	SP16	0.0157	0.0815	0.0032
Burma camp–Circle	SP17	0.0153	0.0851	0.0035
	SP18	0.0114	0.0881	0.0033
	SP19	0.0096	0.0779	0.0029
	SP20	0.0107	0.0938	0.0033

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