


Research Article

Environmental and health risks of potentially toxic element concentrations in soil and foodstuffs from Abuakwa South Municipality, Ghana

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Abstract

Bioaccumulation of potentially toxic elements in soil and foodstuffs from mining areas contaminates foods and threatens public health. Understanding the distribution of Potentially Toxic Elements (PTEs) concentrations is necessary for monitoring environmental and human health risks. The present study assessed the concentrations of PTEs in soil and foodstuffs from small-scale artisanal mining (SAM) communities and their environmental and health risks in the Abuakwa South Municipality (ASM) of Ghana. Soil, plantain, and cocoyam leaves were sampled for PTEs analysis in 11 communities. Soil samples were collected using a 30 x 30-meter quadrat, with three samples taken at a depth of 0-20 cm within four quadrats per community. Environmental pollution indices of the PTEs, including contamination factor (CF), enrichment factor (EF), and geoaccumulation index (Igeo), as well as human health hazard index (HI), were calculated. The CF, EF and Igeo indices of the PTEs decreased in the order Hg > Mn > Cu > As > Ni > Co > Fe > Cr (34.94 to 0.09), Hg > Mn > Ni > Cu > As > Co (649.76 to 1.30) and Hg > Mn > As > Cu > Ni > Co > Fe (5.30 to 4.09), respectively with an overall pollution load index of 0.11 for the soil samples. The concentration of PTEs in plantain and cocoyam decreased in the order Ni > Fe > Co > Pb > Mn > Cu > Hg > As > Cr and Ni > Fe > Co > Pb > Mn > Cu > As > Hg > Cr, respectively, implying Ni, Fe and Co dominance in the foodstuffs. The HI recorded in plantain in all sampling locations exceeded the threshold value of >1 for both adults and children, indicating significant health risks.

Keywords: Cocoyam leaves, Environmental and human health, Heavy metals, plantain, Pollution indices

INTRODUCTION

Globally, small-scale artisanal mining for gold (Au) employs millions of people in local communities but can lead to environmental pollution and public health risks.

Due to the increase in small-scale artisanal mining (SAM), environmental pollution and human health risks are significant concerns in countries where artisanal mining is prevalent. According to Khan *et al.* (2015), potentially toxic elements accumulate in soils and water

bodies through mining activities and amalgams, posing health risks to humans who consume water and foodstuffs grown in contaminated soils and freshwater bodies. Potentially toxic elements (PTEs) usually refer to metallic elements are elements with high density (typically $>5 \text{ g/cm}^3$), such as mercury and lead, which can be toxic to humans at low concentrations. Besides mercury (Hg), which is directly employed in extracting gold, other PTEs such as arsenic (As), manganese (Mn), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn) are released during mining processes into the environment (Balali-Mood *et al.*, 2021). For instance, washing gold in the SAM process relies on water, which is sourced from and returned to water bodies that also serve as a source of drinking water for communities, thereby compromising the water quality for human consumption and the soil quality for food crop production (Attua *et al.*, 2014).

At low concentrations, most PTEs can be toxic to terrestrial ecosystems and human well-being; however, Fe, Cr, and Zn also provide essential micronutrients for human health in small amounts (Harvard University, 2017). However, ingesting large amounts of PTEs can lead to neurological health risks such as insomnia, tremors, memory loss, weak muscles and headaches, kidney and heart defects (Basu *et al.*, 2023; Mohammadi *et al.*, 2020). Artisanal small-scale miners, farmers, fishermen, and unborn babies of pregnant women using contaminated sources are exposed to PTEs health risks such as congenital (birth) disabilities and even death (WHO 2017).

Originating in the 18th century as a grassroots industry, small-scale artisanal mining (SAM), often referred to as 'galamsey,' flourished in Ghana as a household economy. The miners integrate intensive human labour with low-cost machines and informal oversight (Bansah *et al.*, 2016; McQuilken and Hilson, 2016). To regulate small-scale mining, Ghana enacted a Mineral Act in 1962 and subsequent legislative landmarks, including the 1989 Small-Scale Mining Law and the 2006 Minerals and Mining Act, to usher SAM into formal recognition. However, the miners must navigate a complex web of regulations, including age and citizenship screening, to obtain licenses under the 2006 Minerals and Mining Act. As a result, the miners find it attractive to operate outside the legal boundaries of SAM, leading to shadow economies that are supported by tacit community approval (McQuilken and Hilson, 2016; Adu-Baffour *et al.*, 2021).

In recent years, concerns have arisen about the levels of PTE concentrations in cultivated soil and food crops in mining areas, due to the high levels of indiscriminate mining and environmental pollution (Mensah *et al.*, 2025). Although Ghana imposed a temporary ban on all forms of SAM in 2017, the repercussions of the ban reverberated widely among the local communities. The

ban led to a search for alternative livelihoods, extending into the rich natural resource deposits of Abuakwa South Municipality. The proximity of forest reserves and agricultural lands to mining sites in the municipality suggests potential soil, food, and public health risks from PTEs.

However, there is currently no information on the concentration levels of PTEs in the Municipality (ASMA 2018). Understanding the distribution and levels of PTEs in the soil and foodstuffs of the municipality is crucial for monitoring environmental and human health risks.

Previous studies have examined the socioeconomic and health impacts of artisanal and small-scale mining in Ghana (Quarm *et al.*, 2022), environmental consequences (Donkor *et al.*, 2006) and the impact on livelihoods (Chupezi *et al.*, 2009). Research reports on previous studies on PTEs in soil and foodstuffs have little or no reference to the Abuakwa South Municipality (Amaglo and Nyarko (2012), Lam *et al.* (2023) and Darko Asamoah *et al.* (2024). Therefore, the present study aimed to examine the concentration levels of PTEs (Co, Cu, Fe, Mn, Ni, Pb, Cr, Cd, As, and Hg) in soil and foodstuffs of SAM communities, as well as their environmental and health risk implications in the Abuakwa South Municipality of Ghana.

MATERIALS AND METHODS

Study area

The study was conducted in eleven selected communities in the Abuakwa South Municipality (ASM) in the Eastern Region of Ghana (Fig. 1). The ASM shares boundaries with Atiwa District to the North-West, Kwaebibirem District to the South-West, Abuwakwa North Municipality and Fanteakwa District to the East. New Juaben Municipal and Suhum-Krabo-Coaltar Districts are its southern boundaries. The ASM was carved out of the then East Akim Municipal in 2018, covering a total land area of about 725 km^2 with Kibi as its capital. Kibi is approximately 55 km from Koforidua, 105 km from Accra, and 179 km from Kumasi. The area experiences dry (November to March) and wet (April to October) seasons, and its topography is generally undulating, rising between 240m and 300m above sea level, with the highest point being 350m in the Atiwa range. The municipality is endowed with gold and bauxite deposits in commercial quantities, making small-scale mining popular and affecting forests, farms, soils, and rivers, such as the River Birim (Ocansey, 2013).

The eleven selected communities included Atiwa, Apapam (APA), Adadientem (ADA), Kibi Deaf (KD), Steel Bridge (SB), Appetite, Esikan, Suppong, Okyerema, Oben ne Oben and Nsu Abraewa. These communities were noted for SAM and had the potential for bioaccumulation of PTEs in soil and food crops.

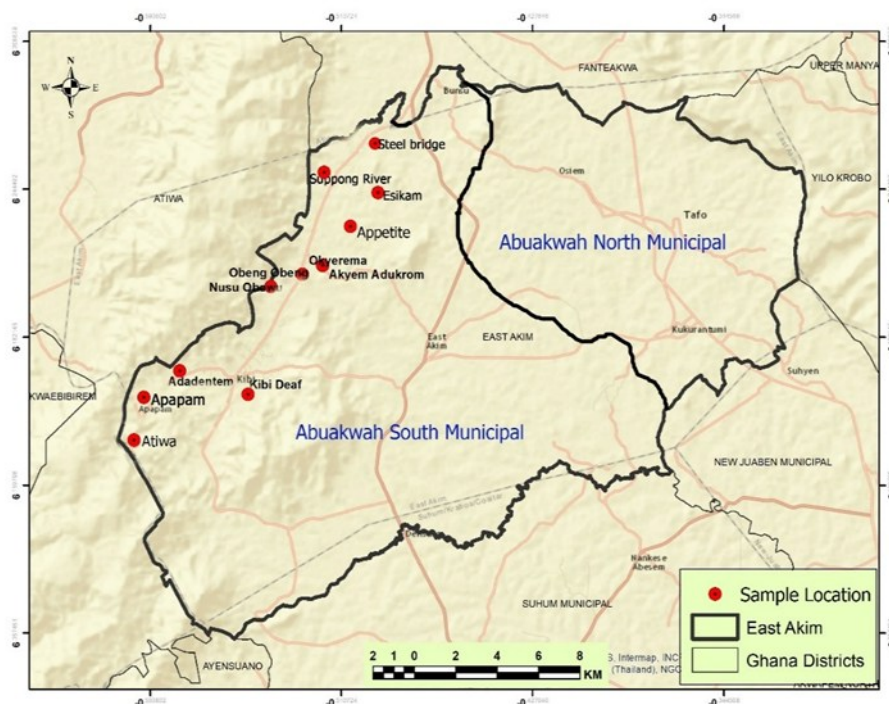


Fig. 1. Map of the study area with sample locations in selected communities of the Abuakwa South Municipality

Soil sampling

Soil samples were collected from the eleven communities along River Birim during the wet season. In each community, four quadrats measuring 30 x 30 meters were established to ensure representative coverage of the study area. Within each quadrat, three soil samples were randomly collected from depths of 0 to 20 cm using an auger (FAO, 2006). These samples were combined to create a composite sample for each quadrat, a common practice for minimizing spatial variability in soil analysis (Carter and Gregorich, 2007).

All samples were placed in well-labeled polythene sampling bags and transported to the University of Ghana Ecological Laboratory for preparation and analysis. The soil samples were air-dried at room temperature for three days. After drying, foreign materials such as gravel, plant residues, and other debris were removed to avoid contamination during analysis (Carter and Gregorich, 2007). The soil was then ground using a porcelain mortar and pestle and sieved through a 2mm nylon sieve for PTEs analysis (Alloway, 2013).

Sampling of selected foodstuffs

Cocoyam (*Colocasia esculenta*) leaves (kontomire) and plantains (*Musa* sp.), which were common foodstuffs cultivated in the study area, were randomly sampled in five communities near the soil sampling sites. In the other six communities, no farming activities existed due to the destruction of farmland by illegal mining. Three samples of cocoyam leaves and three samples of plantain fingers from different plants were randomly sampled within each of the four quadrats in the five commu-

nities (Okechukwu *et al.*, 2020). These samples were then stored in clean, well-labelled plastic bags and transported to the laboratory for analysis.

The cocoyam leaves were thoroughly washed and shredded, while the plantain fingers were peeled, washed, and shredded. All samples were then allowed to stand for two hours for the water to strain off. Each sample was re-bagged into labelled paper bags and oven-dried at 70 to 80 °C to attain a constant mass. The dried samples were then ground using a porcelain mortar and pestle and sieved through a 2mm nylon sieve to obtain a smooth mixture for digestion and chemical analysis at the laboratory (Boahen *et al.*, 2024)

Acid digestion of samples and determination of heavy metals

A 0.1-1.0 g sample of the dried soil and food crop samples was digested with 3 mL of concentrated hydrochloric acid. HNO₃ in Folin-Wu tubes in an electrically heated block for 1 hour at 145 °C. Four millilitres (4 ml) of HClO₄ were then added and heated to 240 °C for an additional hour. The content was diluted to 100 ml with deionized water. "The supernatant was then used to determine heavy metals using the PinAccl 900TAAS" (Blancher *et al.*, 1965).

A 100ml of the digested samples were kept in distilled water and atomized. Analytical blanks were prepared for each sample and quantified using a well-calibrated PerkinElmer PINAAcle 900T Atomic Adsorption Spectrophotometer (AAS). Based on Beer-Lambert Law, the absorbance obtained was used to calculate the heavy

metal concentration levels in the soil and food samples. Light was generated from a hollow cathode lamp at a wavelength characteristic of each analyte. Each analyte was atomized using an atomizer to create free atoms from the samples. Air acetylene gas was used as the energy source to produce free atoms for Cd, Cu, Pb, Cr, Mn, Fe, Ni, and Co, and argon-acetylene gas was used for Hg and As.

Each sample was introduced as an aerosol into a flame burner, aligned with an optical path that allowed the light beam to pass through the flame and absorb the light. The absorbed light was then directed through a monochromator to isolate specific analytical wavelengths of the light emitted by the hollow cathode lamp from the non-analytical wavelength. The sensitive light detected then measured the light and translated the response into analytical measurements. Each heavy metal's final concentration (mg/ kg) was then determined using equation (Eq.) one.

Final concentration (mg/kg) = Concentration x volume of extract / sample weight

Eq. (1)

The respective heavy metal concentrations were compared with European Environmental Agency (EEA) (2007) standard values for soil and food crops (Table 1).

Estimating environmental health risks of artisanal mining-related Potentially toxic elements (PTEs)

Several pollution indices were used to examine the environmental health of the PTEs in the soil samples. Pollution indices were used to estimate the individual metals (Holtra and Zamorska, 2020), expressed as contamination factors, enrichment factors, geoaccumulation indices, and pollution load indices. These indices complement each other to provide a comprehensive understanding of the environmental health risks of the pollutants.

Contamination factor

The contamination factor (*CF*) refers to the extent of contamination of a given heavy metal in comparison to a reference (background or control value) as shown in Eq. 2.

$$CF = \frac{C_{hm}}{C_b} \quad \text{Eq. (2)}$$

The computed *CF* values can be explained as follows: $CF < 1$ indicates low contamination, $1 < CF \leq 3$ indicates moderate contamination, $3 < CF \leq 6$ indicates high contamination, and $CF > 6$ indicates very high contamination (Keshavarzi and Kamar, 2020).

Enrichment factor

The enrichment factor (*EF*) estimates the quantity of a specific heavy metal from anthropogenic activities in the natural environment (Ahamad *et al.*, 2020). The *EF*

Table 1. European Environmental Agency (EEA) guideline values for Potentially toxic elements (PTEs) in soil

Metal	Soil (EEA, 2007)
As	4.5
Cd	1
Cr	N/A
Cu	3.5
Hg	1.9
Ni	230
Co	
Pb	55
Zn	NA
Fe	
Mn	N/A

helps to differentiate between the natural state and anthropogenic contribution to heavy metal concentrations in an environment. In calculating *EF*, a reference element such as scandium (Sc), titanium (Ti), and manganese (Mn), iron (Fe), or aluminium (Al) relative to an element of interest is required (Amin *et al.*, 2009). Iron (Fe) was used as the reference or background metal. The formula for calculating the *EF* was expressed as shown in Eq. 3.

$$EF = \frac{PTE_s/PTE_b}{Fe_s/Fe_b} \quad \text{Eq. (3)}$$

Where Fe_s and Fe_b are the concentrations of each Potentially Toxic Element (PTE) in the sample and the background (reference value), respectively, while Fe_s and Fe_b are the concentrations of iron in the sample and the background, respectively. The estimated *EF* values can be categorized into seven classes (Table 2) (Keshavarzi and Kamar., 2020).

Geoaccumulation index

The geoaccumulation index (*Igeo*) evaluates the intensity of PTEs in the environment due to anthropogenic activities over time (Barbieri, 2016). It is calculated as expressed in Equation 4 (Keshavarzi and Kamar, 2020; Lam *et al.*, 2023).

$$Igeo = \log_2 \frac{PTE_s}{1.5 \times PTE_b} \quad \text{Eq. (4)}$$

Where PTE_s and PTE_b are Potentially Toxic Elements concentrations of a sample of interest and geochemical background value, respectively, while 1.5 allows natural fluctuations of a given metal in the environment. The computed *Igeo* can be interpreted using Table 3 (Keshavarzi and Kamar., 2020).

Pollution load index

The pollution load index (*PLI*) estimated the total con-

Table 2. Enrichment factor range and their interpretations

Range category	Interpretation
EF < 1	No enrichment
1 ≤ EF < 3	Less enrichment
3 ≤ EF < 5	Moderate enrichment
5 ≤ EF < 10	Moderately high enrichment
10 ≤ EF < 25	High enrichment
25 ≤ EF < 50	Very high enrichment
EF > 50	Exceptionally high enrichment

Source: Keshavarzi and Kamar (2020).

Table 3. Geoaccumulation index range and their interpretations

Range	Interpretation
Igeo ≤ 0	No pollution
Igeo (0 – 1)	Moderate pollution
Igeo (1 – 2)	Strong Pollution
Igeo (2 - 3)	High pollution
Igeo (3 – 4)	Very High pollution
Igeo (4 – 5)	Severe pollution
Igeo ≥ 5	Exceptionally high pollution

tamination extent. The *PLI* is a simpler method for assessing the deterioration of soil conditions resulting from the accumulation of PTEs (Kowalska *et al.*, 2018). As shown in Eq. 5, the *PLI* can be calculated by obtaining the n-root of the product of all the contamination factors for each PTEs (*CF_i*) in the area.

$$PLI = \sqrt[n]{(CF_1 CF_2 \times CF_3 \times \dots \times CF_n)} \quad \text{Eq. (5)}$$

where n denotes the number of elements. The *PLI* was used to estimate the total degree of PTEs contamination in the soils to compare the pollution levels of different places within the study area. In other words, an estimated *PLI* value demonstrates the deterioration of a given environment, such as soil conditions due to PTEs accumulation (Kowalska *et al.*, 2018).

A zero (0) *PLI* value implies No background concentration; 0 < *PLI* ≤ 1 implies Unpolluted. Also, estimated *PLI* values of 1 < *PLI* ≤ 2 imply Moderate to Unpolluted, while values of 2 < *PLI* ≤ 3 imply Moderately polluted as compared to 3 < *PLI* ≤ 4, which imply Moderately to highly polluted. In addition, *PLI* values between 4 < *PLI* ≤

5 imply Highly polluted, while a *PLI* > 3 implies Very highly polluted (Jorfi *et al.*, 2017).

Estimating human health risks

Human health indices (HHIs) estimate the health effects of human exposure to carcinogenic and non-carcinogenic chemicals (Kamuda *et al.*, 2016) in food crops (foodstuff). Estimated Daily Intake (EDI) of Potentially Toxic Elements, hazard index (HI), target hazard quotient (THQ) and Cancer Risk Pathways (CRP), assessing the potential health risks associated with long-term ingestion, inhalation and dermal contact of PTEs through food, water and other substances (Ametepey *et al.*, 2018).

Estimated Daily Intake

The estimated daily intake (*EDI*) refers to the quantity of a particular PTEs that an individual ingests daily through various exposure pathways, such as food crops (Ekhaton *et al.*, 2017). The calculation of EDI depends on the daily intake of PTEs-contaminated food crops by an individual and the individual's body weight, which is thus expressed as Eq. 6.

$$EDI = \frac{C_{pte} \times D_{fi}}{BW_a} \quad \text{Eq. (6)}$$

Where *C_{pte}* is the Potentially Toxic Elements concentration in food crops in mg/kg, *D_{fi}* is the daily intake of food in kg person⁻¹, and *BW_a* represents the average body weight in kg of an adult 18years and above is 70 kg and children 1-11years is 30kg (Ekhaton, *et al.*, 2017). Table 4 presents parameters used in the EDI calculation through the oral route. However, the EDI does not directly explain the health effects of PTE intake by a person.

Target Hazard Quotient and Hazard Index

Non-cancer risk of a single element was examined using the target hazard quotient (*THQi*). The *THQi* represents the ratio of the determined dose of a given PTE to a reference level considered harmful to a person's health (Ekhaton *et al.*, 2017; Lam *et al.*, 2023). It is (*THQi*) calculated as the probability of an individual suffering from an adverse health effect of consuming PTE contaminated food relative to an oral reference dose (*RfDi*) of estimated daily intake (in mg/kg-day),

Table 4. Parameters used in the estimation of Estimated daily intake EDI

Parameter	Unit	Quantity for adult	Source
Body weight average (BW _a)	Kg	70	Kamunda <i>et al.</i> (2016)
Daily food intake (Cocoyam leaves)	Kg/person	0.0022	Ametepey <i>et al.</i> (2018)
Daily food intake (Plantain)	Kg/person	0.02	Patrick-Iwuanyanwu and Udowelle. (2017)

Table 5. Oral Reference dose for different heavy metals

PTEs	Oral RfD	Source
Co	0.2	Kamunda <i>et al.</i> (2016)
Cu	0.042	Ametepey <i>et al.</i> (2018)
Fe	0.7	Ametepey <i>et al.</i> (2018)
Mn	0.014	Ametepey <i>et al.</i> (2018)
Ni	0.02	Kamunda <i>et al.</i> (2016)
Pb	0.0036	Kamunda <i>et al.</i> (2016)
Cr	0.003	Kamunda <i>et al.</i> (2016)
Hg	0.0003	Kamunda <i>et al.</i> , 2016
As	0.0003	Kamunda <i>et al.</i> , 2016
Cd	0.0005	Kamunda <i>et al.</i> , 2016

mathematically expressed as in Eq. 7.

$$THQ_i = \frac{EDI_i}{RfD_i} \quad \text{Eq. (7)}$$

THQ has no unit (Kamunda *et al.*, 2016), but a value suggests a high potential health risk (Table 5).

The total non-cancer risk from multiple HMs was assessed using the hazard index (*HI*), which is the sum of the *THQ_i* (Eq. 8).

$$HI = \sum THQ_i$$

RESULTS

Concentrations of heavy metals in soil in Abuakwa South Municipality

Table 6 presents the average concentrations of PTEs in the soil samples in all eleven (11) communities. The copper (Cu) concentrations ranged from 10.17 mg/kg at Suppong to 22.60 mg/kg at Kibi Deaf. These concentrations were within the safe limits of the EEA (2007) standards, as Cu had no specific reference limit. Cobalt (Co) concentration ranged from 10.27mg/kg at Esikam to 40.73 mg/kg at Oben ne Oben. Esikam also recorded the lowest iron (Fe) concentration of 2724 mg/kg, while Oben ne Oben recorded the highest value of 11771 mg/kg. Similarly, manganese (Mn) concentration ranged from 27.97 mg/kg at Steel Bridge (SB) to 116.33 mg/kg at Atiwa. The mean Nickel (Ni) concentrations ranged from 40.05 mg/kg at Steel Bridge to 69.85 mg/kg at Esikam. All these concentrations were within the recommended limit (<230 mg/kg) of the EEA. For mercury (Hg) concentrations, Suppong recorded the lowest value of 1.26 mg/kg, while the highest value of 3.32 mg/kg was recorded at Nsu Abraewa. The remaining communities (locations) showed concentrations lower than the EEA standard (guideline)

Similarly, arsenic (As) concentrations ranged from 0.93 mg/kg at Suppong to 2.39 mg/kg at Oben ne Oben, which was within the safe limit (<43 mg/kg) according to the EEA guideline.

Lead (Pb), Cadmium (Cd), and chromium (Cr) concen-

trations were below the detection limit EEA guideline value of 26 mg/kg of Hg in all the study communities. The lowest concentration of Arsenic (As) was recorded at APA, with the highest concentration of 2.39 mg/kg recorded at Oben ne Oben.

Potentially toxic elements in foodstuff samples in the Abuakwa South Municipality

Table 7 presents the mean concentration of heavy metals in cocoyam leaf and plantain samples.

The mean concentration of Cu in the cocoyam leaves ranged from 12.07 mg/kg at Kibi Deaf to 16.00 mg/kg at Apapam, while Co ranged from 49.23 mg/kg at Kibi Deaf to 71.97 mg/kg at Apapam. Atiwa recorded the highest concentration of Fe (151.27 mg/kg), while Steel Bridge recorded the lowest (149.53 mg/kg). The mean Mn concentration ranged from 34.03 mg/kg at Apapam to 67.50 mg/kg at Adadientem. The mean Ni concentration ranged from 236.97 mg/kg at Adadientem to 276.43 mg/kg at Apapam, while Pb concentrations ranged from 38.37 mg/kg at Atiwa to 52.87 mg/kg at Adadientem. The concentration of Cr was below detection limits. The Hg ranged from 0.013 mg/kg at Apapam to 0.02 mg/kg at Atiwa, Adadientem, Kibi Deaf, and Steel Bridge, while the As ranged from 0.002 at Steel Bridge to 0.02 at Atiwa.

On the other hand, all plantain samples analyzed contained PTEs except for Cr and Cd. Out of the 11 communities where the study occurred, only four (4) communities had plantain growing, as most of the lands and farms in the other communities were destroyed by illegal miners. The mean concentration of Cu ranged from 9.53 mg/kg in Adadientem to 11.07 mg/kg at Apapam, while Co ranged from 50.1 mg/kg at Atiwa to 65.43 mg/kg at Kibi Deaf. Atiwa recorded the lowest concentrations (163.21 mg/kg) of Fe, while Kibi Deaf and Adadientem recorded the highest concentration of 172.4 mg/kg. The Mn concentrations ranged from 13.6 mg/kg at Atiwa to 62.97 mg/kg at Kibi Deaf. The highest Nikle concentration (278.93 mg/kg) was recorded at Apapam, while Adadientem recorded the lowest concentration (242.27 mg/kg). Lead (Pb) concentration ranged from 32.03 mg/kg at Atiwa to 82.3 mg/kg at KD. Chromium (Cr) was, however, below detection limits. The lowest concentration (0.028 mg/kg) of Hg was recorded at Atiwa, while Adadientem and Kibi Deaf recorded the highest concentration of 0.04mg/kg. Similarly, APA recorded the lowest concentrations of As with 0.013 mg/kg, while the highest value of 0.03 mg/kg was recorded at Atiwa.

Environmental health risk of Potentially Toxic Elements (PTEs) in Abuakwa South Municipality

Table 8 presents results for the estimated contamination factor (CF), Enrichment factor (EF), and geoac-

Table 6. Concentration of potentially toxic elements (mg/kg) in soil samples during the wet season in Abuakwa South Municipality

Site	Cu	Co	Fe	Mn	Ni	Pb	Cd	Cr	Hg	As
Atiwa	19.83 ± 2.61	36.9 ± 4.1	6249.67 ± 483.73	116.33 ± 29.1	59.43 ± 3.52	BD	BD	BD	2.81 ± 1.17	0.96 ± 0.1
APA	11.83 ± 3.66	33.4 ± 4.39	5416.33 ± 442.59	54.27 ± 11.42	46.23 ± 3.79	BD	BD	BD	1.949 ± 0.28	0.94 ± 0.01
ADA	14.46 ± 4.46	24.63 ± 4.14	10212.67 ± 2610.55	51.67 ± 15.5	64.6 ± 6.52	BD	BD	BD	1.49 ± 0.49	1.446 ± 0.54
KD	22.6 ± 3.35	34.86 ± 2.4	7659 ± 1324.7	75.27 ± 11.49	63.63 ± 7.73	BD	BD	BD	2.92 ± 1.84	1.79 ± 0.34
SB	18.83 ± 1.5	19.27 ± 3.3	3325.33 ± 626.9	27.97 ± 6.09	40.05 ± 0.49	BD	BD	BD	2.01 ± 1.06	2.19 ± 0.44
Appetite	17.7 ± 4.28	23.75 ± 2.53	4916 ± 1512.32	43.93 ± 9.91	53.85 ± 7.73	BD	BD	BD	1.81 ± 0.36	1.56 ± 0.68
Esikam	18.12 ± 2.61	10.27 ± 6.24	2724 ± 511.03	44.07 ± 10.27	69.58 ± 3.36	BD	BD	BD	2.07 ± 0.15	1.29 ± 0.48
Suppong	10.17 ± 0.93	27.1 ± 4.14	4470.67 ± 1029.39	49.37 ± 3.15	54.23 ± 5.31	BD	BD	BD	1.26 ± 0.22	0.93 ± 0.42
Okyerema	13.8 ± 2.35	36.13 ± 5.75	11598.33 ± 2710.64	55.17 ± 7.47	44.93 ± 10.72	BD	BD	BD	2.22 ± 0.43	1.66 ± 0.39
Oben ne Oben	22.17 ± 8.33	40.73 ± 2.87	11771 ± 3085.7	29.8 ± 9.37	45.5 ± 4.28	BD	BD	BD	2.27 ± 0.33	2.39 ± 0.53
Nsu Abraewa	17.1 ± 2.75	37.87 ± 8.25	9971.33 ± 1626.41	40.33 ± 8.97	65.33 ± 9.7	BD	BD	BD	3.32 ± 0.91	2.04 ± 0.39

*BD = Below detection limit

Table 7. Concentration of heavy metals in cocoyam leaves and plantain in Abuakwa South Municipality

Site	Cu	Co	Fe	Mn	Ni	Pb	Cr	Cd	Hg	As
Acceptable Standards@	73.3	0.05	425.5	500	67.9	0.1	1.3	0.2	0.01	0.1
Cocoyam leaves (<i>Colocasia esculenta</i>)										
Atiwa	13.27 ± 1.63	68.1 ± 1.84	151.27 ± 8.75	47.33 ± 2.57	276.43 ± 15.97	38.37 ± 3.9	BD	BD	0.02 ± 0.003	0.02 ± 0.007
APA	16 ± 1.28	71.97 ± 3.33	150.1 ± 3.27	34.03 ± 4.21	254.9 ± 42.32	48.17 ± 2.9	BD	BD	0.013 ± 0.003	0.04 ± 0.002
ADA	15.47 ± 0.83	63.97 ± 2.21	155.87 ± 6.6	67.5 ± 10.93	236.97 ± 26.66	52.87 ± 6.31	BD	BD	0.014 ± 0.004	0.05 ± 0.005
KD	12.07 ± 1.99	49.23 ± 2.67	150.93 ± 3.0	40.37 ± 6.33	244.27 ± 46.02	51.07 ± 7.92	BD	BD	0.02 ± 0.006	0.01 ± 0.004
SB	13.47 ± 0.98	63.07 ± 2.41	149.53 ± 2.01	42.73 ± 4.65	272.2 ± 9.95	46.93 ± 3.64	BD	BD	0.02 ± 0.002	0.002 ± 0.0007
Plantain (<i>Musa sp.</i>)										
Atiwa	10.07 ± 1.7	50.1 ± 5.01	153.2 ± 4.52	36.9 ± 5.74	242.27 ± 25.83	32.03 ± 13.71	BD	BD	0.028 ± 0.006	0.03 ± 0.008
APA	11.07 ± 1.63	58 ± 3.93	163.21 ± 8.11	49.97 ± 5.87	278.93 ± 18.42	62.3 ± 11.72	BD	BD	0.039 ± 0.007	0.013 ± 0.005
ADA	9.53 ± 1.04	56.93 ± 1.62	165.07 ± 6.84	48 ± 2.65	246.47 ± 7.35	50.27 ± 8.33	BD	BD	0.04 ± 0.007	0.02 ± 0.005
KD	10.13 ± 0.35	65.43 ± 4.53	172.4 ± 8.55	62.97 ± 7.1	249.53 ± 13.21	82.3 ± 24.18	BD	BD	0.04 ± 0.01	0.02 ± 0.007

@ (Ashraf et al., 2021 ; Zango et al., 2013)

Table 8. Contamination factor, enrichment factors and geoaccumulation index of soil samples during the wet season in Abuakwa South Municipality

Heavy metals	Atiwa	Apapam	Adadi-etem	Kibi Deaf	Steel Bridge	Appetite	Esikam	Suppong	Okyrema	Obene Oben	Nsu Abrewa	Overall mean
Contamination factor (CF)												
Mn	3.72	3.99	5.26	5.54	3.05	3.44	3.81	3.09	3.98	3.40	3.23	3.86
Fe	0.09	0.12	0.06	0.08	0.10	0.08	0.09	0.08	0.09	0.09	0.10	0.09
Cu	0.33	0.19	0.25	0.41	0.37	0.55	0.45	0.20	0.31	0.44	0.40	0.35
Ni	0.27	0.52	0.07	0.04	0.04	0.05	0.21	0.49	0.24	0.26	0.15	0.21
Co	0.08	0.12	0.12	0.11	0.13	0.08	0.10	0.11	0.08	0.10	0.10	0.10
Hg	29.51	31.94	40.28	25.69	30.21	33.33	28.82	41.32	45.49	36.81	40.97	34.94
As	0.24	0.28	0.31	0.32	0.28	0.29	0.24	0.28	0.28	0.22	0.30	0.28
Enrichment factor (EF) of soil samples during the wet season												
Mn	42.44	29.59	70.29	71.20	24.05	38.58	43.98	41.73	44.14	39.48	27.96	43.04
Fe	4.53	1.79	5.12	5.56	4.21	4.04	4.37	2.40	2.87	5.27	3.08	3.93
Cu	1.54	0.79	2.60	17.79	10.18	13.97	19.07	14.53	10.62	12.30	13.38	10.62
Co	1.15	0.79	2.23	1.54	1.06	1.33	1.01	1.43	1.09	1.47	1.17	1.30
Hg	572.99	397.61	1313.76	567.04	468.32	572.84	538.43	826.67	660.88	693.89	534.92	649.76
As	2.90	2.29	5.59	3.90	2.99	3.12	3.05	3.56	3.20	3.11	2.78	3.32
Geoaccumulation index (Igeo) of soil samples during the wet season												
Mn	5.01	5.11	5.51	5.59	4.72	4.90	5.05	4.74	5.11	4.88	4.81	5.04
Fe	-3.99	-3.59	-4.71	-4.29	-3.87	-4.23	-4.00	-4.29	-4.06	-4.01	-3.91	-4.09
Cu	-2.17	-2.97	-2.59	-1.85	-2.00	-1.45	-1.74	-2.91	-2.29	-1.77	-1.91	-2.15
Ni	-2.47	-1.53	-4.48	-5.07	-5.28	-5.02	-2.84	-1.61	-2.65	-2.50	-3.33	-3.34
Co	-4.26	-3.60	-3.62	-3.73	-3.57	-4.17	-3.86	-3.84	-4.20	-3.88	-3.88	-3.87
Hg	5.08	5.19	5.52	4.88	5.11	5.25	5.04	5.56	5.70	5.39	5.55	5.30
As	1.06	1.30	1.43	1.49	1.30	1.33	1.03	1.26	1.30	0.98	1.38	1.26
PLI	0.09	0.09	0.09	0.12	0.10	0.11	0.11	0.11	0.11	0.11	0.12	0.11

CF, EF and Igeo could not be calculated for Cr, Cd and Pb because the concentrations were below detection limits

commulation index (Igeo) of the measured PTEs in the soil samples. The environmental pollution indices of CF, EF and Igeo had decreasing mean values in the order Hg>Mn> Cu> As> Ni>Co> Fe> (34.94 to 0.09), Hg>Mn>Ni>Cu> As> Co (649.76 to 1.30) and Hg>Mn> As>Cu> Ni>Co> Fe (5.30 to -4.09), respectively with an overall PLI of 0.11. This (Igeo) shows most of the soil samples were not polluted. Only a few exhibited extreme pollution levels. The mean Igeo for Mn was extreme in 54.55% of the samples, with the remaining 45.45% exhibiting severe pollution. All the soil samples showed no pollution from Fe, Ni, and Co. Mercury pollution was, however, extreme for all the samples while Arsenic Igeo showed strong soil pollution for all samples.

However, 81.82% of the samples showed extreme Mn pollution, while the remaining 18.18% had severe Mn pollution. Iron, Ni, Cu, and Co showed no pollution in all samples. Hg pollution was severe in 36.36% of the samples, with the remaining 63.64% recording very high Hg pollution. There was no As pollution in 36.36% of samples, while the remaining 63.64% of samples showed moderate As pollution. The estimated soil pollution load index (PLI) values showed various locations were unpolluted.

Human health risks of PTEs in foodstuffs in Abuakwa South Municipality

Tables 9 and 10 present the Estimated Daily Intake (EDI), the Target Hazard Quotient (THQ), and the Hazard Index (HI) for the foodstuffs (plantain and cocoyam) samples. The EDI of Co in cocoyam leaves ranged from 5.06×10^{-4} to 2.13×10^{-3} mg/kg/day in adults and from 1.68×10^{-5} to 7.54×10^{-5} in children. The EDI of Cu ranged from 4.17×10^{-4} to 4.86×10^{-3} mg/kg/day in adults and from 1.26×10^{-5} to 1.67×10^{-5} mg/kg/day in children. Similarly, the EDI of Fe ranged from 40.70×10^{-3} mg/kg/day to 4.89×10^{-3} mg/kg/day in adults and from 1.56×10^{-4} to 1.63×10^{-4} mg/kg/day in children, while for Mn, the value ranged from 1.06×10^{-3} to 2.12×10^{-3} mg/kg/day in adults and from 3.56×10^{-5} to 7.07×10^{-5} mg/kg/day in children. For Ni, the EDI value ranged from 7.45×10^{-3} to 8.69×10^{-3} mg/kg/day in adults and from 2.48×10^{-4} to 2.89×10^{-4} mg/kg/day in children. For Pb, the EDI ranged from 1.21×10^{-3} to 1.66×10^{-3} mg/kg/day in adults and for children, it ranged from 1.41×10^{-5} to 1.41×10^{-4} mg/kg/day. The concentrations of Cd and Cr were below the detection limit, so their EDI, THQ, and HI could not be determined. In addition, Steel Bridge had no plantain farm or crop at the time of the study.

The EDI of Co in plantain ranged from 1.43×10^{-2} to 1.86×10^{-2} mg/kg/day in adults and from 4.77×10^{-4} to 6.23×10^{-4} mg/kg/day in children. For Cu, EDI ranged from 2.72×10^{-3} mg/kg/day to 3.15×10^{-3} mg/kg/day in adults and from 9.08×10^{-5} to 1.05×10^{-4} mg/kg/day in

children. The EDI values for Fe ranged from 4.93×10^{-3} to 4.72×10^{-2} mg/kg/day in adults and from 1.46×10^{-3} to 1.64×10^{-3} mg/kg/day in children while Mn value ranged from 1.05×10^{-2} to 1.80×10^{-2} mg/kg/day in adults and in children, it ranged from 3.51×10^{-4} to 5.90×10^{-4} mg/kg/day. The EDI of Ni in plantain ranged from 6.92×10^{-2} to 7.96×10^{-2} in adults and from 2.26×10^{-3} to 4.78×10^{-3} mg/kg/day in children. Similarly, Pb EDI ranged from 9.15×10^{-3} to 2.35×10^{-2} mg/kg/day in adults and for children, it ranged from 3.05×10^{-4} to 3.05×10^{-4} mg/kg/day. The elements Cd and Cr had concentrations below the detection limit, and therefore, their EDI, THQ, and HI could not be determined.

For all the EDI values, corresponding THQ values revealed that for Cocoyam leaves, Co, Cu, Fe, Mn, Ni, Pb, As, and Hg all had individual THQ values less than 1 for adults 18 years and above, which implies that the values were safe for humans. The corresponding HI values were also < 1 except for the HI recorded at Adadientem, which slightly exceeded a threshold of 1. For children, the THQ values recorded were also less than 1 except for Pb values recorded at Adadientem and Kibi D leaf and Ni values recorded at Atiwa. Meanwhile, the HI values recorded for children aged 1-11 years for the elements had values greater than 1, which implied that children aged 1-11 years would develop health risk complications if exposed to cocoyam leaf consumption at the various sampling locations.

The THQ values for plantain were greater than 1 (>1) for all samples, indicating that the levels of Co, Cu, Fe, Mn, Ni, Pb, As, and Hg were all unsafe. Specifically, the THQ values for adults (18 years and older) exceeded the threshold value of 1 (>1) for Pb and Ni. For Mn, the THQ values exceeded 1 at the Steel Bridge and Apapam sampling locations but were below 1 at the other locations. In contrast, the THQ values for Co, Cu, and Fe for adults were within the threshold value of 1. For children (1-11 years), the THQ values for Pb, Ni, and Mn exceeded 1 at all sampling locations, whereas the values for Fe, Cu, and Co were below 1. The HI values for adults and children were greater than 1 at all sampling locations, indicating a high probability of adverse health effects associated with consuming plantain within the study area (Tables 9 and 10).

DISCUSSION

Potentially toxic element concentration in soil at Abuakwa South Municipality

In the study of soil in Abuakwa South Municipality, the mean concentrations of potentially toxic elements (PTEs) were found to decrease in the order: Fe > Mn > Ni > Co > Cu > Hg > As. The relatively high iron (Fe) and manganese (Mn) concentrations in the study areas (Table 6) do not pose significant health risks. Iron is

Table 9. Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) for cocoyam leaves and plantain samples during the wet season

Heavy metal	Atiwa			Apapam			Adadientem			Kibi Deaf			Steel Bridge		
	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ
Co	5.06x 10 ⁻⁴	0.011	0.011	2.26x 10 ⁻⁷	0.011	0.011	2.13x 10 ⁻³	0.010	0.010	0.010	1.55x 10 ⁻³	0.008	0.008	1.98x10 ⁻³	0.011
Cu	4.17x10 ⁻⁴	0.009	0.009	5.03x10 ⁻⁴	0.012	0.012	4.86x 10 ⁻³	0.012	0.012	0.012	3.79x 10 ⁻⁴	0.009	0.009	4.23x10 ⁻⁴	0.010
Fe	4.75x 10 ⁻³	0.007	0.007	4.71x 10 ⁻³	0.007	0.007	4.89x 10 ⁻³	0.007	0.007	0.007	4.74x 10 ⁻³	0.007	0.007	4.70x10 ⁻³	0.007
Mn	1.49x 10 ⁻³	0.011	0.011	1.06x 10 ⁻³	0.076	0.076	2.12x 10 ⁻³	0.152	0.152	0.152	1.27x 10 ⁻³	0.091	0.091	1.34x10 ⁻³	0.096
Ni	8.69x 10 ⁻³	0.434	0.434	8.01x 10 ⁻³	0.400	0.400	7.45x 10 ⁻³	0.372	0.372	0.372	7.67x 10 ⁻³	0.384	0.384	8.55x10 ⁻³	0.428
Pb	1.21x 10 ⁻³	0.349	0.349	1.5x 10 ⁻³	0.421	0.421	1.66x 10 ⁻³	0.462	0.462	0.462	1.60x 10 ⁻³	0.458	0.458	1.47x 10 ⁻³	0.409
Hg	6.29x 10 ⁻⁷	0.002	0.002	4.09x 10 ⁻⁷	0.001	0.001	4.4x 10 ⁻⁷	0.001	0.001	0.001	6.29x 10 ⁻⁷	0.002	0.002	6.29x10 ⁻⁷	0.002
As	6.29x 10 ⁻⁷	0.002	0.002	1.26x 10 ⁻⁶	0.004	0.004	1.57x 10 ⁻⁶	0.005	0.005	0.005	3.14x 10 ⁻⁷	0.001	0.001	6.29x10 ⁻⁷	0.002
HI		0.825	0.825		0.932	0.932		1.021	1.021	1.021		0.96	0.96		0.965

Plantain - Adults 18 years and above of body weight of 70kg															
Co	Atiwa			Apapam			Adadientem			Kibi Deaf			Steel Bridge		
	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ
Co	1.43x 10 ⁻²	0.072	0.072	1.66x 10 ⁻²	0.083	0.083	1.63x 10 ⁻²	0.081	0.081	0.081	1.86x10 ⁻²	0.093	0.093	-	-
Cu	2.88x10 ⁻³	0.069	0.069	3.15x 10 ⁻³	0.075	0.075	2.72x10 ⁻³	0.065	0.065	0.065	2.89x 10 ⁻³	0.069	0.069	-	-
Fe	4.38x10 ⁻²	0.625	0.625	4.66x 10 ⁻²	0.067	0.067	4.72x 10 ⁻²	0.067	0.067	0.067	4.93x 10 ⁻³	0.070	0.070	-	-
Mn	1.05x 10 ⁻²	0.753	0.753	1.43x10 ⁻²	1.012	1.012	1.37x 10 ⁻²	0.979	0.979	0.979	1.80x 10 ⁻²	1.285	1.285	-	-
Ni	6.92x 10 ⁻²	3.461	3.461	7.96x10 ⁻²	3.984	3.984	7.04x 10 ⁻²	3.521	3.521	3.521	7.12x 10 ⁻²	3.565	3.565	-	-
Pb	9.15x 10 ⁻³	2.542	2.542	1.78x10 ⁻²	4.944	4.944	1.44x 10 ⁻²	3.989	3.989	3.989	2.35x 10 ⁻²	6.532	6.532	-	-
Hg	8.06x10 ⁻⁶	0.026	0.026	1.11x10 ⁻⁵	0.003	0.003	1.14x 10 ⁻⁵	0.038	0.038	0.038	1.14x 10 ⁻⁵	0.038	0.038	-	-
As	8.57x10 ⁻⁶	0.028	0.028	2.6x 10 ⁻⁴	0.866	0.866	5.71x 10 ⁻⁵	0.019	0.019	0.019	5.71x 10 ⁻⁵	0.019	0.019	-	-
HI		7.576	7.576		11.034	11.034		8.759	8.759	8.759		11.671	11.671	-	-

Table 10. Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI) for cocoyam leaves and plantain samples during the wet season

Cocoyam leaves- Children (1-11) years of body weight 30kg	Atiwa			Apapam			Adadientem			Kibi Deaf			Steel Bridge		
	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ	EDI	THQ	THQ
Co	1.68x 10 ⁻⁵	0.025	0.025	7.54x 10 ⁻⁵	0.026	0.026	7.12x 10 ⁻⁵	0.023	0.023	0.023	5.16x 10 ⁻⁵	0.018	0.018	6.61x 10 ⁻⁵	0.023
Cu	1.39x10 ⁻⁵	0.023	0.023	1.67x 10 ⁻⁵	0.028	0.028	1.62x 10 ⁻⁵	0.027	0.027	0.027	1.26x 10 ⁻⁵	0.021	0.021	1.41x 10 ⁻⁵	0.024
Fe	1.58x 10 ⁻⁴	0.016	0.016	1.57x 10 ⁻⁴	0.016	0.016	1.63x 10 ⁻⁴	0.016	0.016	0.016	1.58x 10 ⁻⁴	0.016	0.016	1.56x 10 ⁻⁴	0.016
Mn	4.96x 10 ⁻⁵	0.248	0.248	3.56x 10 ⁻⁵	0.178	0.178	7.07x 10 ⁻⁵	0.354	0.354	0.354	4.23x10 ⁻⁵	0.211	0.211	4.47x 10 ⁻⁵	0.232
Ni	2.89x 10 ⁻⁴	1.013	1.013	2.67x 10 ⁻⁴	0.935	0.935	2.48x 10 ⁻⁴	0.869	0.869	0.869	2.55x 10 ⁻⁴	0.896	0.896	2.85x 10 ⁻⁴	0.998
Pb	1.41x 10 ⁻⁵	0.782	0.782	6.61x 10 ⁻⁵	0.981	0.981	1.56x 10 ⁻⁵	1.077	1.077	1.077	4.47x 10 ⁻⁵	1.040	1.040	4.92x 10 ⁻⁵	0.956
Hg	1.47x 10 ⁻⁶	0.004	0.004	9.53x 10 ⁻⁷	0.003	0.003	1.02x 10 ⁻⁶	0.003	0.003	0.003	1.47x 10 ⁻⁶	0.004	0.004	1.47x 10 ⁻⁶	0.004
As	1.47x 10 ⁻⁶	0.004	0.004	2.93x 10 ⁻⁶	0.009	0.009	3.66x 10 ⁻⁶	0.012	0.012	0.012	7.33x 10 ⁻⁷	0.002	0.002	1.47x 10 ⁻⁶	0.004
HI		2.115	2.115		2.176	2.176		2.381	2.381	2.381		2.208	2.208		2.257
Plantain - Children (1-11) years of body weight 30kg															
Co	4.77x 10 ⁻⁴	0.167	0.167	5.5x 10 ⁻⁴	0.193	0.193	5.42x 10 ⁻⁴	0.189	0.189	0.189	6.23x 10 ⁻⁴	0.218	0.218	-	-
Cu	9.60x 10 ⁻⁵	0.159	0.159	1.05x 10 ⁻⁴	0.176	0.176	9.08x 10 ⁻⁵	0.151	0.151	0.151	9.65x 10 ⁻⁵	0.161	0.161	-	-
Fe	1.46x 10 ⁻³	0.146	0.146	1.55x 10 ⁻³	0.155	0.155	1.57x 10 ⁻³	0.157	0.157	0.157	1.64x 10 ⁻³	0.164	0.164	-	-
Mn	3.51x 10 ⁻⁴	1.757	1.757	4.76x 10 ⁻⁴	2.379	2.379	4.57x 10 ⁻⁴	2.285	2.285	2.285	5.90x 10 ⁻⁴	2.998	2.998	-	-
Ni	2.31x 10 ⁻³	8.076	8.076	2.26x 10 ⁻³	9.289	9.289	2.35x 10 ⁻³	8.216	8.216	8.216	4.78x 10 ⁻³	8.317	8.317	-	-
Pb	3.05x 10 ⁻⁴	5.932	5.932	5.93x 10 ⁻⁴	11.537	11.537	4.78x 10 ⁻⁴	9.309	9.309	9.309	7.84x 10 ⁻⁴	15.240	15.240	-	-
Hg	1.86x 10 ⁻⁵	0.062	0.062	2.60x 10 ⁻⁵	0.086	0.086	2.67x 10 ⁻⁵	0.088	0.088	0.088	2.65x 10 ⁻⁵	0.088	0.088	-	-
As	2.50x 10 ⁻⁵	0.066	0.066	8.66x 10 ⁻⁶	0.028	0.028	1.33x 10 ⁻⁵	0.044	0.044	0.044	1.33x 10 ⁻⁵	0.044	0.044	-	-
HI		16.365	16.365		23.843	23.843		20.439	20.439	20.439		27.230	27.230	-	-

one of the most abundant elements on Earth and serves as a crucial micronutrient for human and plant growth. Its availability is influenced by soil pH and bicarbonate concentration (Hochmuth, 2017).

Similarly, the high levels of manganese detected in all samples are not deemed hazardous to health. Manganese, which constitutes approximately 0.1% of the Earth's crust, is an essential plant nutrient that plays a vital role in several physiological processes, particularly photosynthesis (WHO, 2005). In natural soils, the total concentration of manganese can range from less than 1 mg/kg to 4000 mg/kg dry weight, with mean values around 300–600 mg/kg dry weight (Howe *et al.*, 2005). The concentrations found in Abuakwa South Municipality were within this range but remained below the mean values.

The results showed that the mean Nickel (Ni) concentration was within safe levels. Igneous rocks are known to be the primary source of Nickel (Ni) in soils. However, anthropogenic sources, such as fertilizers, may also introduce the metal into the soil. In natural soil, the concentration of Nickel ranges from 10 to 1000 mg/kg. However, the concentration can be reduced by leaching or runoff through soil particles and harvested food crops (Chauhan *et al.*, 2008). Excessive intake of nickel can have severe adverse effects on human health, potentially leading to cancer, allergies, and diminished lung function (Zambelli *et al.*, 2016; El-Naggar *et al.*, 2021).

Lead (Pb) concentration in the soil samples was below the detection limit. Lead can persist in the soil for extended periods. However, if the concentration remains below 150 mg/kg, there is no significant risk of lead exposure (Stehouwer, 2010). Non-essential PTEs, including Pb, can have detrimental effects on plants, including reduced biomass accumulation, inhibited photosynthesis, stunted growth, chlorosis, disrupted water balance, impaired nutrient assimilation, and accelerated senescence (Balkhair and Ashraf, 2016; Collin *et al.*, 2022).

Chromium (Cr) is commonly found in the trivalent state but may also be in the hexavalent state, and occurs naturally in rocks, plants, volcanic dust, and gases, as well as in animals. The level of chromium in soil may vary depending on the area and degree of anthropogenic contamination. Within the study area, notably a gold mining area, chromium concentration was below the detection limit for all samples. However, similar studies in a Southern Nigerian gold mining site showed relatively higher Cr concentration (Abiya *et al.*, 2018). Similarly, Cd was below the detection limit in all soil samples.

The results (Table 6) showed that the mean concentrations of mercury (2.5 – 4.4 mg/kg) were similar to that of Gbani, a mining community in the Upper East Re-

gion of Ghana. The Gbani community, where small-scale artisanal gold mining takes place, had a mean Hg concentration of 71 mg/kg (Gyamfi *et al.*, 2020). Mercury (Hg) has no known essential biological function (Wuana and Okieimen, 2011). Its concentration in agricultural soils may be influenced by the parent material forming the soil, as well as soil properties such as soil organic matter, soil microbes, pH, and other anthropogenic activities, including non-ferrous mining, petroleum refining, and industrial waste, which also influence its concentration (Zhong *et al.*, 2016).

The presence of copper (Cu) in soils of mining and agricultural communities may originate from non-ferrous metal mining, such as gold, copper, lead, zinc, and tin, as well as copper-based fungicides and copper smelting (Quan-Ying *et al.*, 2014). It may also originate from agricultural sources, such as manure, sewage sludge, mineral fertilisers, and pesticides. Relatively high copper concentration in soils within the study may be attributed to mining activities, though all concentrations were lower than the world average shale value (45 mg/kg). A related study in Tarkwa, a gold-mining Ghanaian community, also revealed a similar range (6.5 mg/kg – 56.17 mg/kg) (Bentum *et al.* (2011).

The highest As concentration was recorded in Oben ne Oben with values of 2.39 mg/kg. The concentration of As was within the permissible limit. Arsenic (As) may occur naturally in soils. It may also be introduced into soils from mining waste, especially in mining areas, waste sludge, and phosphate fertilizers (Punshon *et al.*, 2016). The global total As concentration is 5 mg/kg, although this may vary with geographic locations and the parent material from which the soil is formed (Punshon *et al.*, 2016).

Potentially toxic elements concentration in foodstuff at Abuakwa South Municipality

The concentration of PTEs in plantain (*Musa paradisiaca*) was generally higher than in the cocoyam leaves (*Colocasia esculenta*). The mean concentrations in plantain decreased in the order of Ni>Fe> Co> Pb>Mn> Cu> Hg>As, while that of cocoyam leaves was in the decreasing order; Ni>Fe> Co> Pb>Mn> Cu> As> Hg, respectively. The mean concentrations of Mn, Fe, and Cu in foodstuffs from the various sampling locations were within the WHO/FAO recommended limits of 500, 425.5, and 73.3 mg/kg, respectively (Table 7), which do not pose public health concerns for consumers. In contrast, the mean concentrations of Hg, Co, Pb, and As in foodstuffs from these locations exceeded the WHO/FAO recommended limits of 0.001, 0.05, 0.1 and 0.1, respectively.

Iron (Fe), As, Co, Cu, Mn, and Ni are essential for the growth of living organisms in smaller quantities. At higher concentrations, however, it is toxic, not only to

humans but can create conditions unfavourable for other living organisms to thrive. Metals like Cd and Cr concentrations were below the detection limit. They are well-known for their negative effects, such as gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, immune system dysfunction, birth defects, cancer, and sometimes death (Balali-Mood *et al.*, 2021).

Plantain is a staple food commonly consumed in various forms within the study area. It plays a significant role in the preparation of fufu, which is pounded together with cassava. Additionally, plantain is often boiled, whether ripe or unripe, and typically served with a cocoyam leaf sauce, known locally as 'kontomire' stew. Another popular method of consumption in the region is roasting plantains and eating them with groundnuts, a widely consumed combination across Africa.

Concentrations of Cd and Cr in cocoyam leaves were also below detection limits. Generally, the Fe concentrations were relatively high at Atiwa, Apapam (APA), Adadientem (ADA), Kibi Deaf (KD), and Steel Bridge (Table 7) (but higher than those reported by Amaglo and Nyarko (2012) in vegetables from northern, Upper East and Ashanti regions. The range for manganese was similarly higher in this study.

Ecological risk of potentially toxic heavy metal concentration in soils of Abuakwa South

The estimated environmental pollution indices of CF, EF, and Igeo revealed mercury (Hg) is potentially toxic to the environment in the study area. The results showed a decreasing contamination factor (CF) of Hg > Mn > Cu > As > Ni > Co > Fe, with mean values ranging from 34.94 to 0.09. The relatively high ecological risk of Hg is consistent with the report by Lam *et al.*, (2023). The high mercury contamination factor in all soils raises concerns about regulating the use of mercury in the gold washing and extraction process.

Concerning the origin of the pollutants, the study revealed that enrichment of the metals ranged from no enrichment (for metals below detection, such as chromium and cadmium) to exceptionally high enrichment in metals like manganese and mercury in soils. The estimated enrichment factor (EF) was in the order of Hg > Mn > Ni > Cu > As > Co, ranging from 649.76 to 1.30. This suggests that contamination by potentially toxic elements (PTEs) primarily stems from anthropogenic sources rather than natural ones. The possible sources of the observed EF sequence include mining activities and agriculture. In areas where agriculture was non-existent due to farm destruction caused by mining activities, mining was identified as the primary source of pollution.

Other elements, such as arsenic, nickel, and copper, also showed varying degrees of enrichment. From these degrees of enrichment, severe to extreme mercury

and manganese pollution was recorded in the soils at all sampling locations, with generally strong arsenic pollution.

The geoaccumulation index (Igeo) of individual PTEs in the sequence of Hg > Mn > As > Cu > Ni > Co > Fe, ranging from 5.30 to -4.09, yielded an overall pollution load index (PLI) of 0.11 in the soil. While Hg and As are biologically non-essential and have no good effect on plant and animal health, Mn is a micronutrient. Manganese serves as an essential cofactor for the oxygen-evolving complex (OEC) of the photosynthetic machinery, catalyzing water-splitting reactions in photosystem II (PSII) (Alejandro *et al.*, 2020). Despite the individual metal pollution levels (Igeo), the PLI shows no pollution in all the samples within the study area because of the low value of 0.11.

Health risk of potentially toxic elements concentration in foodstuffs of Abuakwa South

Plantain sampled during the study recorded an HI > 1, which indicates a high probability of an adverse health effect. The elevated HI value indicates significant PTE contamination in the plantain, posing a significant public health risk to consumers, especially children, who are twice as vulnerable since plantain is a staple food in the area. This result is in line with the findings of Zango, Anim-Gyampo, and Ampadu (2013), who reported HI values of 8.58 to 147.06 for plantain in the Wassa-Amenfi-West District of Ghana, with lead (Pb) identified as a major contributor to health risks. Similar research conducted around Obuasi found that the HI for mercury in plantain exceeded the safe limit of 1 for both adults and children (Addai-Arhin *et al.*, 2022). This necessitates urgent public education and awareness regarding the consumption of plantain from the study area. On the other hand, the majority of cocoyam leaf samples had a Hazard Index (HI) of less than 1 (<1) for adults aged 18 years and above, indicating no significant health risk associated with consumption. This relative safety may be attributed to the shorter growth period of cocoyam leaves before harvest, compared to plantain leaves, which require a longer time to mature. However, this safety margin does not extend to all age groups. If the same cocoyam leaves are consumed by children between the ages of 1 and 11, the HI is greater than 1 (1 >), suggesting a higher likelihood of adverse health effects in children. This highlights the increased vulnerability of children to potential health risks associated with these samples.

Conclusion

The study revealed the presence of PTEs in the soil and foodstuffs, with the exceptions of Cr, Cd, and Pb in the soil and Cr and Cd in the foodstuffs. The PTE concentrations in soil samples were within the safe guide-

lines established by the EEA (2007). The PTEs contamination observed ranged from low to very high, with mercury recording the highest contamination in all samples, indicating significant concern. Despite the high concentrations of certain elements in soil samples, the pollution load index values suggest all sites were unpolluted. For foodstuff samples, cocoyam leaves in all sample locations had hazard index (HI) values <1 for adults, indicating no adverse health effects. However, the recorded HI value was greater than 1 for children aged 1-11 years, posing health risks to this age group. The plantain samples, however, had a recorded hazard index greater than 1 for all samples, indicating a high probability of an adverse health effect when consumed by both children and adults. Measures should be taken to address high mercury contamination by illegal small-scale mining in the area. Specific interventions should be designed to protect children from consuming contaminated foodstuffs, especially cocoyam leaves and plantains. Public awareness campaigns on the health risks of consuming contaminated food should also be conducted, especially for children.

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Data Availability

Data will be made available upon request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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