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Health Risks of Potentially Toxic Elements in Soils and Vegetables from Artisanal Gold Mining Communities in Ghana's Amansie West District

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Abstract

Due to the discharge of potentially toxic elements (PTEs) into agricultural soils, artisanal and small-scale mining (ASM) operations have intensified environmental degradation and public health risks. This study investigates the concentrations, transfer dynamics, and health effects of PTEs in six ASM-affected communities in Ghana's Amansie West District. A total of 90 soil samples and 60 vegetable samples (tomato, cabbage, and onion) were assessed for PTEs, and the results were used to estimate bioaccumulation, bioconcentration and health-risk indices. Lead (Pb) levels ranged from 4.94 to 9.42 mg/kg, mercury (Hg) from 0.78 to 2.55 mg/kg, while arsenic (As) in soil samples exceeded the FAO/WHO limits for safe agriculture. The soil's pH range (4.41 - 5.20) indicated acidic conditions that enhance metal mobility and plant absorption. Bioconcentration coefficients (BAC) for As and Hg exceeding 1.0 indicated that these metals were effectively transferred from soil to edible vegetable parts. Health risk assessments revealed Hazard Indexes (HI) values above 1 for adults in Datanor (1.13) and Tontokrom (1.27), while child HI values exceeded the safe threshold of 1.0 in all six communities, indicating serious non-carcinogenic risks. Carcinogenic risk (CR) for arsenic varied from 1.4×10^{-4} to 2.3×10^{-4}, suggesting a potential lifetime risk of cancer above the USEPA recommendation of 1.0×10^{-4}. The findings demonstrate the need for sustained environmental monitoring, food-safety management, soil remediation and public-health interventions in ASM-affected communities.

Keywords

Artisanal and Small-Scale Mining (ASM), Potentially Toxic Elements, Health Risk Assessment, Soil Contamination, Food Safety

1. Introduction

Artisanal and small-scale gold mining (ASM) is an important source of livelihood in Ghana but can contribute to the release of potentially toxic elements (PTEs) into agricultural soils and the food Chain. The silent and slow threat of environmental contamination from artisanal and small-scale mining (ASM) is one enduring and little-known issue, though. The soil in Ghana's ASM communities continues to "speak" despite being overshadowed by national discourse and political changes. It bears the silent burden of public health hazards as well as the scars of potentially toxic element contamination.

Amansie West District in the Ashanti Region is the best illustrated paradox, where unregulated mining activities expose indigenes to high concentrations of potentially toxic elements (PTEs), which have long-term consequences for ecosystem health, food security, and human well-being [1] [2].

Over 30% of Ghana's gold production comes from artisanal small-scale gold mining, which provides a living for over a million Ghanaians [3]. However, its impact on the environment is oddly significant due to widespread land degradation, processing of ore based on mercury, and insufficient regulatory oversight. PTEs such as arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), copper (Cu), chromium (Cr), and nickel (Ni) contaminate agricultural soils and water bodies due to the frequent overlap of mining sites and agricultural lands [4] [5].

It is commonly known that some PTEs are toxic, persistent in the environment, and bioaccumulate in food chains [6]. After building up in the soil, they are taken up by edible crops and then consumed by humans, posing both carcinogenic and non-carcinogenic health risks [7] [8].

The persistence of PTE in the soil has a serious negative influence on the health of the environment. For example, exposure to arsenic is linked to skin lesions, cardiovascular disorders, and several carcinogenic diseases; lead affects a child's neurological system and cognitive development; and mercury, which is commonly used in ASM, harms the kidneys and central nervous system [9].

After years of continuous exposure, these effects, which are often undetectable in the early stages, become more pronounced. In rural areas where vegetable cultivation and borehole water use are common, cumulative exposure through the food chain and drinking water significantly raises health risks [10].

Recent studies have shown that vegetables grown in contaminated soils, such as cabbage, tomato, and onion accumulate high concentrations of PTEs, often exceeding the acceptable limits set by the WHO and FAO [6]. These findings suggest that the soil is no longer just a substrate for food production but is now a centre for PTEs. Health risk assessments in mining areas are still insufficient, despite the clear evidence of pollution and vulnerability among the populace in districts like Tarkwa-Nsuaem, Prestea-Huni Valley, and Amansie West.

Furthermore, sustainable management of ASM requires greater consideration of environmental health, food safety and agricultural soil quality. Unfortunately, little is known about comprehensive health risk assessments and their implications in Ghana, specifically in the Amansie West District. The current government and some journalists have implemented strategies to combat illegal ASM activities in Ghana. The UN's Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-Being), SDG 6 (Clean Water and Sanitation), and SDG 15 (Life on Land), cannot be achieved if ASM communities continue to face unchecked pollution and public health neglect. Politicians and policymakers need to move past election rhetoric to address the "toxic legacy" of ASM operations, which still endangers soil fertility, agricultural productivity, and human health [11] [12].

Therefore, the purpose of this study is to conduct a comprehensive health risk assessment of potentially toxic elements in edible plants and soil within communities impacted by artisanal mining in the Amansie West District.

Three objectives are involved in the study:

1) To ascertain the levels of key PTEs in agricultural soils and widely consumed vegetables (onions, tomatoes, and cabbage).

2) To quantify the bioaccumulation and transfer of PTEs from soil to vegetables.

3) To assess the potential non-carcinogenic and carcinogenic health risks associated with consumption of vegetables.

In Ghana's mining-affected areas, especially the Amansie West District, this study is crucial for environmental health, food safety, and sustainable agriculture. It provides empirical proof of the degree of PTE contamination of the soil and vegetables in the communities impacted by mining.

2. Materials and Methods

2.1. Description of Study Area

The study area, which is one of the largest districts in Ashanti and makes up around 5.4% of the Ashanti Region's total land area, is situated within latitudes 6˚ North: 7˚ North and longitudes 2˚ West and 3˚ West. It covers an area of roughly 1364 square kilometers, as seen in **Figure 1**.

The district has significant gold mineralization and extensive artisanal and small-scale gold mining (ASM) activity.

Tontokrom, Datanor, Keniago, Watreso, Dunhura, and Asamang are some of the major communities engaged in artisanal mining. Major crops like cassava, yam, cocoyam, and some vegetables were once grown in these communities, providing food for Kumasi and the surrounding area. In order to buy food for their livelihood, the local population prefers to walk to nearby villages that have not been impacted by the spread of ASM activities, which have contaminated the environment and reduced soil fertility.

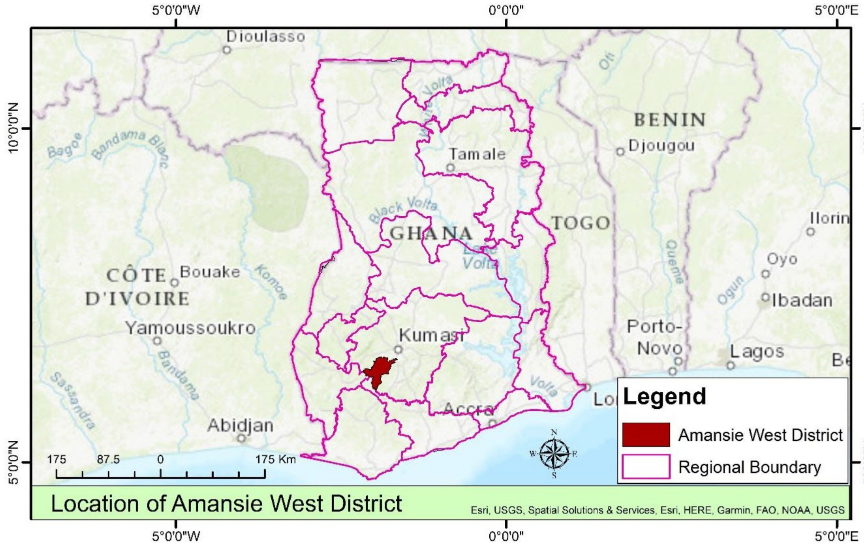

Figure 1. Location of Amansie West District; Source: Authors' own construct.

The district has a humid, semi-equatorial climate, which is characterized by a bimodal rainfall pattern with major and minor wet seasons. There are two rainfall peaks during the main rainy season, which runs from March to July. September through November are the off-peak months for the wet season. The annual rainfall ranges from 855 mm to 1,500 mm. The average annual number of rainy days is between 110 and 120. Generally speaking, December through March are dry months with high temperatures and chilly, rainy, and foggy mornings [13].

The soil is predominantly Orthic Ferralsol (highly weathered, iron-rich soils) and Dystric Fluvisol (acidic, alluvial soils) soil types.

2.2. Sampling Strategy

According to Agricultural Extension Officers of the Ministry of Food and Agriculture (MOFA), six agricultural communities were badly affected by the ASM operations. These communities used to be agricultural communities in the district, which served Kumasi and its environs with foodstuffs. Unfortunately, with the advent of ASM activities, these communities have been badly affected by chemical pollution, and topsoil, which contains nutrients, has been removed as a result of this menace. The communities were Tontokrom, Datanor, Keniago, Watreso, Dunhura, and Asamang. Therefore, the focus of this study was on these communities.

A total of 90 composite soil samples and 60 edible vegetable (tomato, cabbage, and onion) samples were collected from active farming plots within the six mining-impacted communities during the dry season (January-February 2023). For each of the six communities, 15 composite soil samples were randomly collected from agricultural plots at 0 - 20 cm depth using a stainless-steel auger, while 10 composite vegetable samples per species were collected from the same farming areas. The vegetables were harvested by uprooting them manually from the soil and separated into roots and edible portions using sharp scissors. The samples were then kept in well-labelled Ziploc bags and transferred to the laboratory for analysis.

2.3. Sample Preparation and Analysis

Soil samples were air-dried, ground, and sieved through a 2 mm mesh sieve. Soil pH was measured using a 1:2.5 soil-to-water suspension with a calibrated pH meter following standard procedures [14]. Additionally, vegetable samples were rinsed with deionized water, oven-dried at 65˚C for 72 h, ground, and sieved. Individual vegetable (tomato, cabbage and onion) samples were analyzed separately for community- and species-specific PTE concentrations and transfer calculations. Where applicable, samples were subsequently composited for community-level risk assessment. This enabled us to calculate bioconcentration factors and health risk indices (carcinogenic and non-carcinogenic) for each community.

Aqua regia (1 HNO_3:3 HCl) was prepared and used to digest about 1.0 g of each sample (soil and vegetable), allowed to cool, filtered, and decanted after 30 minutes. Atomic Absorption Spectrophotometry (AAS) (Model: Agilent 200) was then used to measure the concentrations of arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) in the soils and vegetables. Additionally, a vapor generation accessory (VGA) and AAS were used to measure mercury in both samples. The Global Soil Laboratory Network (GLOSOLAN) certified reference standards were used for instrument calibration, and procedural blanks were added to guarantee analytical accuracy.

2.4. Quality Assurance and Quality Control (QA/QC)

To ensure data reliability, duplicate samples, reagent blanks, and certified reference materials (GL0-10 for soil) were added to the samples and analyzed. The percentage recovery and the relative standard deviation of target metals were estimated using the relation: Quality Assurance and Quality Control (QA/QC)

$$\text{Recovery Percentage}(\%) = \left(\frac{\text{Measured soil concentration}}{\text{Certified value from reference material}}\right) \times 100 \quad (1)$$

And

$$\text{RSD}(\%) = \left(\frac{\text{Standard deviation}}{\text{Mean}}\right) \times 100 \quad (2)$$

The accuracy and effectiveness of an analytical method in measuring metals in a sample are estimated by the percentage recovery [15].

The recovery percentages of the various PTEs were Pb (85% - 112%), As (88% - 115%), Cd (110% - 119%), Cu (89% - 97%), and Zn (85% - 115%). All values fell within the acceptable limits (80% - 120%) specified by the USEPA [15] guidelines, depending on the specific PTE. The lowest detectable limits for all the PTEs established were Pb: 0.0100 mg/kg, As: 0.0030 mg/kg, Cd: 0.0020 mg/kg, Hg: 0.0020 mg/kg, Cu: 0.0030 mg/kg, and Zn: 0.0010 mg/kg. With a correlation coefficient of 0.994 to 0.998, the calibration lines were linear. All analyses were conducted in triplicate, the average taken, and the results were expressed in mg/kg on a dry weight basis. Additionally, the data were subjected to descriptive analysis using OriginPro version 2022b (Origin Lab Corporation of Northampton, USA), in which mean values were determined.

We also used the Shapiro-Wilk test to make sure the data had a normal distribution before performing the various tests. In this case, variables were assumed to have a normal distribution if $P > 0.05$ but not if $P < 0.05$. Differences among communities were evaluated descriptively using the reported community-level concentrations and ranges. Because inferential statistical testing was not performed, differences are not interpreted as statistically significant.

2.5. Bioaccumulation Coefficient Calculations

The accumulation of potentially toxic elements (PTEs) by the roots and edible parts of the vegetables was calculated using the bioaccumulation coefficient (BAC) and Bioconcentration Factor (BCF), respectively. BAC measures the transfer of PTEs from soil to edible plant parts (shoots), while BCF measures the transfer from soil to roots. Both indices measure the ability of a plant to accumulate heavy metals from soil into its edible parts [16] [17]. This is given by the relation:

$$BAC = \frac{PTE \text{ concentration in edible part } (shoot)\left(\frac{\text{mg}}{\text{kg}}\right)}{PTE \text{ concentration in soil}\left(\frac{\text{mg}}{\text{kg}}\right)} \quad (3)$$

$$BCF = \frac{PTE \text{ concentration in edible root}\left(\frac{\text{mg}}{\text{kg}}\right)}{PTE \text{ concentration in soil}\left(\frac{\text{mg}}{\text{kg}}\right)} \quad (4)$$

This evaluates how efficiently the vegetables absorb PTEs from soil into their edible parts (shoot system), helps identify hyperaccumulator species for phytoremediation, and assesses bioavailability of metals in soil [16] [17]. According to Yoon *et al.* [16] and Zhuang *et al.* [17], if BAC is greater than one (1), it implies that a high concentration of PTEs is accumulated in the edible part of the vegetables and BAC less than one (1) also implies that the vegetables absorb less of the metal relative to soil concentration. Similarly, BCF values greater than one (1) indicate high root accumulation. Both BAC and BCF are employed in this study to represent soil-to-plant transfer of potentially toxic elements (PTEs).

2.6. Human Health Risk Assessment

Health risk assessment was performed using the United States Environmental Protection Agency (USEPA) risk assessment guidelines [18] [19]. There are three routes of exposure of PTEs to adults and children: Oral ingestion, dermal contact and inhalation [20]. In the six communities of the Amansie West District, oral ingestion and dermal contact were the common routes of exposure; therefore, human health risk assessment was estimated through consumption of contaminated vegetables (oral ingestion) and dermal contact with contaminated soil [20].

2.6.1. Non-Carcinogenic Health Risk Assessment

The Hazard Quotient (HQ) and the Hazard Index (HI) are two measures used to evaluate the potential health risks posed by exposure to environmental contaminants, as well as non-carcinogenic risk. They are commonly used in environmental health risk assessment and toxicology to assess the potential effects of exposure to contaminants in the environment, and in combination with other measures to assess the potential health risks posed by exposure to environmental contaminants [21]. The Hazard Quotient is a measure of the potential health risk posed by exposure to a single contaminant, and by a single contamination pathway or the hazard quotient (HQ) measures the total non-carcinogenic hazards associated with heavy metal intake from regular consumption of contaminated vegetables. It is calculated by dividing the estimated exposure dose of a contaminant by its reference dose, which is the level of long-term exposure considered safe for human health [21] [22].

The Hazard Index is a measure of the potential health risk posed by exposure to multiple contaminants. It is calculated by the summation of the Hazard Quotients for all contaminants of concern in a particular exposure pathway. The HI is useful in evaluating the overall health risk posed by exposure to multiple contaminants [23]. It is assumed that an adverse health effect exists when HQ and HI are above 1, whilst adverse health effects are unlikely at HQ and HI of less than or equal to 1 [21] [22].

In Ghana, tomato, cabbage, and onion are often eaten raw as salad or cooked as stew [24], and some are also consumed by individuals to boost their nutritional health status. Then we first calculated the Estimated Daily Intake (EDI) of possible oral ingestion of the PTEs in mg/kg bodyweight/day:

$$\text{EDI} = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{5}$$

where C = metal concentration in vegetables (mg/kg);

IR = ingestion rate (200 g/day for adults; 100 g/day for children);

EF = exposure frequency (365 days/year);

ED = exposure duration (30 years for adults; 6 years for children);

BW = body weight (70 kg for adults; 15 kg for children);

AT = averaging time (non-carcinogenic: ED × 365; carcinogenic: 70 × 365).

These values were used and reported in previous studies [23] [25].

Hazard quotient (HQ) was then estimated using the formula:

$$\text{HQ} = \frac{EDI}{RfD} \tag{6}$$

where RfD is the PTE oral reference dose as reported by Li *et al.* [21], and Shen *et al.* [26]. (Pb = 0.0035, Cd = 0.001, As = 0.0003, and Hg = 0.0001 mg/kg/day). The value of Hg was reported by Mawari *et al.* [27]. The RfD is the oral ingestion of a daily substance that will not harm a person throughout his/her lifetime. RfD is critical in the EPA's evaluation of non-carcinogenic health risks [28].

The Hazard Index (HI) is therefore estimated using the following relation:

$$HI = \sum HQ_i \tag{7}$$

2.6.2. Carcinogenic Health Risk Assessment

Assessing the risk of carcinogenic soil to human health is a critical component of environmental and public health management. Conducting a risk assessment involves evaluating the exposure to these carcinogens and determining the likelihood of adverse health effects.

The estimated cancer risk (ECR) was calculated as:

$$\text{ECR} = \text{EDI} \times \text{CSF} \tag{8}$$

where CSF is the cancer slope factor (mg/kg/day). CSF of the selected metals was reported in USEPA [19] (Pb = 0.0085, Cd = 0.3800, As = 0.6700, Hg = N/A). The cancer slope factor is an estimate of the probability that an individual will develop cancer if exposed to a chemical substance for a lifetime of 70 years [29]. ECR above 0.0001 is viewed as unacceptable; risks below 0.000001 are not considered to have significant health effects, and risk lying between 0.0001 and 0.000001 is considered an acceptable range [24] [30].

Although the USEPA provides a cancer slope factor for cadmium (Cd) (USEPA, 2011), carcinogenic risk was assessed only for arsenic (As) and lead (Pb), as these elements were identified as the primary carcinogenic contaminants of concern in the study area [24] [29].

3. Results

3.1. Concentrations of Potentially Toxic Elements in Soil

Table 1 shows the levels of potentially toxic elements (PTEs) in agricultural soils in six communities affected by ASM. The PTE concentrations showed notable differences among the six communities. Tontokrom, Datanor, and Keniago typically had high levels of the potentially hazardous elements, probably due to artisanal small-scale mining activities. Tontokrom had the highest concentration of iron (Fe) at 16418.00 mg/kg, which was below the 20,000 mg/kg reference value [31].

Pb, As, Cd, and Hg, the most critical contaminants, were present in high concentrations in Tontokrom, 9.42 mg/kg for Pb, 8.16 mg/kg for As, 2.55 mg/kg for Hg, and 0.78 mg/kg for Cd in Datanor. Pb was above the local tailings background levels of 4.53 mg/kg, despite being below the global soil average of 10 mg/kg [32], implying anthropogenic input.

Tontokrom, Datanor, and Keniago had arsenic concentrations above the typical global background concentration of 5.0 mg/kg [33]. However, these values remain below the cited Dutch Target Value of 29 mg/kg [34]. Similarly, lead concentrations were highest in Tontokrom (9.42 mg/kg), followed by Datanor (8.66 mg/kg) and Keniago (5.83 mg/kg), while substantially lower concentrations were recorded in Dunhura (1.49 mg/kg) and Asamang (0.17 mg/kg). Furthermore, in the same communities, mercury levels exceeded the global soil mean (0.5 mg/kg) and the FAO/WHO permissible level (1.0 mg/kg), indicating widespread contamination brought on by ASM operations.

Table 1. Mean concentrations of PTEs in soil samples (mg/kg).

Community	pH	Fe mg/kg	Mn mg/kg	Pb mg/kg	As mg/kg	Cd mg/kg	Hg mg/kg
Tontokrom	4.52	16418.00	629.48	9.42	8.16	0.67	2.55
Datanor	4.68	14056.00	424.83	8.66	7.70	0.78	1.91
Keniago	4.85	8486.20	292.32	5.83	7.23	0.27	1.12
Watreso	4.91	6508.50	197.88	5.27	3.68	0.23	1.12
Dunhura	5.12	7834.30	141.97	1.49	0.13	0.22	0.36
Asamang	5.20	5579.60	135.91	0.17	0.19	0.05	0.30
Range	-	20,000 – 50,000	200 - 1000	10 - 50	<5.00	0.01 - 0.50	<1.0

Values are means of analytical replicates. Standard deviations are not reported as the study focused on community-level mean concentrations for comparative risk assessment.

3.2. Bioaccumulation Coefficient (BAC) of PTEs in Vegetables across ASM Communities

Across the six artisanal small-scale mining (ASM) communities, there were notable differences in the bioaccumulation coefficient (BAC) of Pb, Cd, As, and Hg in tomato, cabbage, and onion (**Figure 2**).

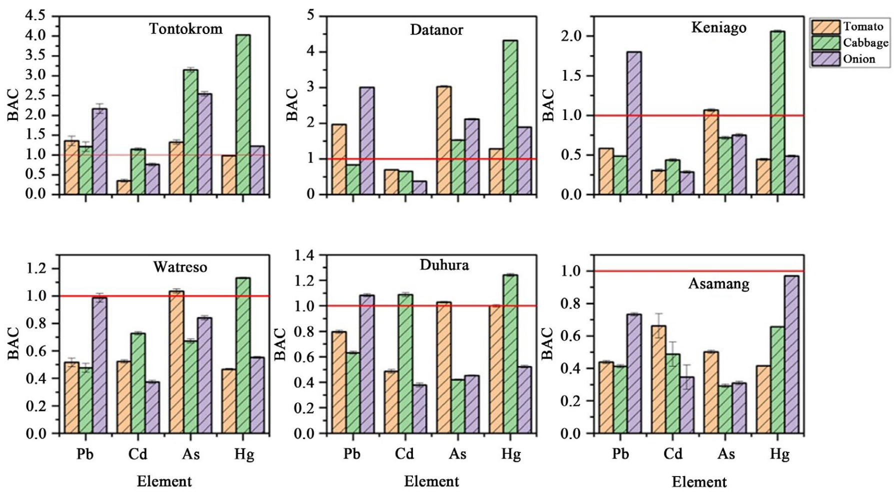

Figure 2. Bioaccumulation coefficient (BAC) of potentially toxic elements in tomato, cabbage and onion in the six ASGM communities. The red lines represent a BAC = 1, above which it indicates effective transfer of toxic elements from soil to edible plant parts.

At Tontokrom, BAC values greater than 1 were observed for several crop-PTE combinations. The strongest transfer was observed for Hg in cabbage (BAC = 4.03), As in cabbage (3.15), As in onion (2.54), and Pb in onion (2.17). Moderate accumulation was seen in tomatoes, especially for Cd (BAC = 1.2). Similarly, in

Datanor, tomatoes accumulated higher levels of Pb (BAC = 1.8) and Cd (BAC = 1.4), while cabbage showed higher accumulations of Hg (BAC = 4.0) and As (BAC = 2.8), surpassing the threshold of 1.0.

In Keniago, cabbage showed higher As uptake (BAC = 1.2), and onion showed markedly higher Pb accumulation (BAC = 1.9). While the majority of the metals in Watreso had BAC values below 1.0, selective uptake was evident in the accumulation of Hg (BAC = 1.1) and As (BAC = 0.9) in cabbage and onions, respectively.

Dunhura recorded BAC near-threshold accumulation for almost all the PTEs, with tomato (Cd = 1.1) and cabbage (Pb = 1.0; As = 1.1) showing slight exceedances of the safe limit. In Asamang, all metals showed BAC values below 1.0, except onion, which approached the threshold for Hg (BAC = 0.9), suggesting relatively lower transfer efficiency in this community.

In comparison to Pb and Cd, As and Hg consistently showed BAC values above 1.0 in the majority of crops, particularly in onions and cabbage, indicating their greater translocation and bioavailability. This pattern suggests that communities affected by mining are at higher risk of dietary exposure to arsenic and mercury.

3.3. Potential Health Risk Associated with Consumption of Vegetables

The vegetables from each community were composited, dried, ground, and analyzed for PTEs. The resulting concentrations were used to estimate health risk factors for adults and children. To assess the potential health risk to adults and children in the six communities from vegetable consumption, the estimated daily intake of PTEs (EDI), hazard quotient (HQ), and hazard index (HI) were calculated. The calculations were made using Equations (3), (4), and (5), respectively, from which non-carcinogenic and carcinogenic health risks were calculated and the results presented.

3.3.1. Estimated Daily Intake (EDI)

Table 2 presents the estimated daily intake (EDI) of PTEs through vegetable consumption for adults and children. Children had higher EDI values due to lower body weight and similar ingestion rates.

Table 2. Estimated daily intake of potentially toxic elements (PTEs) via vegetable consumption.

PTE	Adults (mean)	Children (mean)	Child/Adult Ratio	RfD (mg/kg/day)
Pb	0.0028	0.0065	2.33	0.0035
As	0.0041	0.0096	2.33	0.0003
Cd	0.0004	0.0009	2.33	0.001
Hg	0.0013	0.0030	2.33	0.0001

Child EDI values are based on the stated exposure parameters (IR = 100 g/day, BW = 15 kg, ED = 6 years). The child/adult ratio of 2.33 is a mathematical consequence of these parameters.

3.3.2. Non-Carcinogenic Risk (Hazard Quotient and Hazard Index)

Table 3 presents the Hazard Index (HI) values for adults and children across the six communities. The HI values, which were derived from the summed HQs of individual metals, exceeded the safe threshold of 1.0 for children in all six communities, with the highest values occurring in Tontokrom (2.96) and Datanor (2.63). For adults, HI exceeded 1.0 in Tontokrom (1.27) and Datanor (1.13) but remained below 1.0 in the other four communities. These elevated HI values were driven primarily by arsenic (As) and mercury (Hg), indicating potential non-carcinogenic health concerns, particularly for children.

Table 3. Hazard Index (HI) across communities.

Community	Adults HI	Children HI
Tontokrom	1.27	2.96
Datanor	1.13	2.63
Keniago	0.87	2.03
Watreso	0.75	1.75
Dunhura	0.63	1.47
Asamang	0.59	1.37
Safe Limit	<1	<1

3.3.3. Carcinogenic Risk

Cancer risk (CR) values for As and Pb exceeded the USEPA acceptable limit of 1 × 10^{-4} in Tontokrom and Datanor, especially among children (Table 4). For Pb, CR values exceeded the limit only in Tontokrom (1.1 × 10^{-4} for adults, 0.5 × 10^{-4} for children).

Table 4. Carcinogenic risk (CR) values for As and Pb Across Communities.

Community	CR (As) - Adults	CR (As) - Children	CR (Pb) - Adults	CR (Pb) - Children
Tontokrom	2.4×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	0.5×10^{-4}
Datanor	2.1×10^{-4}	0.9×10^{-4}	0.9×10^{-4}	0.4×10^{-4}
Keniago	1.7×10^{-4}	0.8×10^{-4}	0.7×10^{-4}	0.3×10^{-4}
WHO Limit	$<1 \times 10^{-4}$	$<1 \times 10^{-4}$	$<1 \times 10^{-4}$	$<1 \times 10^{-4}$

4. Discussion

4.1. Elevated Concentrations of Potential Toxic Elements in Soils

The findings indicated that PTE concentrations, including those of arsenic (As), lead (Pb), mercury (Hg), and cadmium (Cd), in soils from mining communities in Amansie West were much higher than background levels and the WHO/FAO-recommended limits for agricultural soils [17]. Communities such as Tontokrom and Datanor recorded elevated As concentrations relative to the cited global background level; however, the reported values remained below the Dutch Target Value of 29 mg/kg [34]. The widespread use of mercury amalgamation in ASM operations and the geological diversity of the Birimian rocks in gold-bearing arsenopyrite minerals are the causes of these elevated levels [5]. Mercury and arsenic tend to remain in the environment and become immobilized in the soils with low pH and organic matter [12]. The mobility of these PTEs increases under acidic soil conditions (pH < 5), enhancing their uptake by plants [35].

4.2. Accumulation of PTEs in Edible Vegetables

Bioaccumulation patterns from the field samples showed that leafy vegetables such as cabbage, tomato, and onion accumulated high levels of As, Pb, and Cd—consistent with prior findings in mining-affected zones in Ghana and Nigeria [36] [37]. The calculated Bioaccumulation Coefficients (BACs) exceeded 1 for many of these PTEs in multiple communities, indicating active transfer from soil to plant tissue.

Vegetables grown in Datanor and Tontokrom registered BAC values for As and Hg above 1.2, confirming their phytoremediation potential but also pointing to significant health risks if consumed regularly. Such high transfer values are particularly high when plant uptake is not matched by environmental regulation or soil immobilization of metals, which again highlights the absence of proper soil management and nutrient buffering in these communities [33].

4.3. Non-Carcinogenic and Carcinogenic Risk Implications

Health risk assessments based on United States Environmental Protection Agency (USEPA) models [19] indicated Hazard Index (HI) values exceeding the safe threshold of 1.0 in most cases for children in all six communities. This outcome suggests a potential for adverse non-carcinogenic health effects, particularly due to exposure to arsenic and mercury. For adults, HI exceeded 1.0 in Tontokrom (1.27) and Datanor (1.13). In these communities, although individual HQ values were below 1 for some metals, cumulative exposure from multiple PTEs resulted in HI values surpassing the threshold. In the remaining communities (Keniago, Watreso, Dunhura, and Asamang), adult HI values remained below 1.0.

Carcinogenic risks (CR) calculated for As and Pb frequently exceeded the acceptable USEPA limit of 1×10^{-4}, especially in children, a group highly susceptible to long-term toxicological effects. Chronic ingestion of arsenic-contaminated vegetables could potentially lead to skin, bladder, and lung cancers, while lead exposure is strongly associated with developmental disorders, particularly in children under 6 years of age [9].

4.4. Health Risk Implications for Adults and Children

The health risk assessment results revealed marked differences in susceptibility between adults and children exposed to potentially toxic elements (PTEs) through vegetable consumption in the ASM-impacted communities. Children consistently exhibited higher hazard quotients (HQ) and hazard indices (HI) compared to adults, owing to their lower body weight, higher food intake per unit body mass, and greater sensitivity to toxicants [19] [38]. For example, the Hazard Index exceeded the safe threshold of 1.0 for children in all six communities, with the highest values in Tontokrom (2.96) and Datanor (2.63), indicating significant non-carcinogenic risks. For adults, HI exceeded 1.0 only in Tontokrom (1.27) and Datanor (1.13), while adult values in the other four communities remained below the threshold. This suggests that children in mining-affected households face a greater likelihood of developing adverse health effects such as impaired growth, cognitive deficits, and organ dysfunction linked to chronic exposure to metals like As, Pb, and Hg [39] [40].

Furthermore, carcinogenic risk (CR) values for arsenic (1.4×10^{-4} - 2.3×10^{-4}) surpassed the USEPA acceptable limit of 1.0×10^{-4}, implying a potential lifetime cancer risk for both adults and children, though children remain at greater long-term risk due to early-life exposures. Chronic exposure to arsenic has been associated with skin lesions, respiratory problems, and increased incidence of internal cancers [41]. Mercury, another prevalent contaminant in the district, poses risks of neurological and developmental disorders, particularly in children, where early exposure may result in irreversible cognitive impairment [42].

For adults, although HI values were generally below the safe threshold, continuous dietary exposure could still lead to cumulative health effects, including kidney dysfunction (from Cd), cardiovascular disorders (from Pb), and neurological effects (from Hg). In contrast, children are more vulnerable to immediate and long-term impacts, raising urgent concerns about food safety in these communities.

The findings underscore the urgent need for dietary advisories, soil remediation, and health surveillance programs to safeguard vulnerable populations. Targeted interventions should prioritize children, who face disproportionately higher risks, while also protecting adults whose prolonged exposure may result in chronic diseases that burden community health systems.

4.5. Policy Implications

The findings of this study emphasize the need for sustained environmental health interventions in communities affected by ASM activities. Priority measures may include the following; routine monitoring of PTEs in agricultural soils and food crops, targeted risk communication and public-health interventions in high-risk communities, and appropriate soil-management and remediation strategies.

These actions are important to safeguard food security and public health in mining-impacted areas and for supporting progress toward the Sustainable Development Goals (SDGs 3, 6, and 15).

5. Conclusions

The findings from this study stress the urgent need for environmental and public health interventions in artisanal and small-scale mining (ASM) communities within the Amansie West District of Ghana. The health risks posed by potentially toxic elements (PTEs) such as arsenic (As), lead (Pb), mercury (Hg), and cadmium (Cd) remain alarming and inadequately addressed. Soil samples from Tontokrom, Datanor, and Keniago recorded arsenic concentrations up to 8.16 mg/kg, lead concentrations reaching 9.42 mg/kg, and mercury levels of 2.55 mg/kg—all above the typical background levels for agricultural soils. In addition, the pH levels ranging from 4.41 to 5.20 indicate acidic soil conditions that enhance metal mobility and bioavailability, further compounding the threat to food safety. Vegetables cultivated in these contaminated soils showed high metal uptake, with bioaccumulation coefficients (BACs) exceeding 1.0 for As and Hg in crops like cabbage, tomato, and onion. This confirms the efficient transfer of metals from soil to edible plant tissues, directly exposing local populations through the food chain.

Additionally, health risk assessments revealed Hazard Index (HI) values for children exceeding 1.0 in all six communities, with the highest values in Tontokrom (2.96) and Datanor (2.63), indicating serious non-carcinogenic health concerns. Carcinogenic risk (CR) for arsenic varied from 1.4×10^{-4} to 2.3×10^{-4}, suggesting a potential lifetime risk of cancer above the USEPA recommendation of 1.0×10^{-4}. These findings highlight the urgent need for sustained environmental monitoring, food-safety management, soil remediation, and public-health interventions in ASM-affected communities.

Author Contributions

Conceptualization: Sadick Adams; Methodology: Sadick Adams, Samuel Kumi, and Sampson Owusu; Data curation and analysis: Sadick Adams, Edem Agbenyo, and Benjamin Ason; Investigation: Sadick Adams and Sampson Owusu; Writing original draft: Sadick Adams and Prince Martin Gyekye; Writing review and editing: all authors; Sadick Adams. All authors read and approved of the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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