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Environmental exposure and potential health impact of heavy metals in previous mining communities in Ghana

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Abstract

Heavy metal exposure arising from metal mining is a significant source of pollution in sub-Saharan Africa. In Ghana, concerns have been heightened due to increasing artisanal mining activities. Although efforts are being made to curb illegal mining activities, including a ban on artisanal mining by the government of Ghana, the devastating impacts of mining activities can persist in the environment for a long period. This study was carried out to assess the impact of mining activities on the exposure of toxic and potentially toxic metals in food, vegetation, soil and water samples from communities where mining activities have been halted for several years. The samples were digested using a microwave digestion system employing a mixture of nitric acid and hydrogen peroxide and analysed for mercury (Hg), lead (Pb), chromium (Cr), copper (Co), manganese (Mn), zinc (Zn), arsenic (As), cadmium (Cd), cobalt (Co), nickel (Ni) and iron (Fe), using an inductively coupled plasma - mass spectrometer (ICP-MS). The results showed generally elevated levels of metals in water, food, vegetation and soils. For example, in vegetation, the average concentrations of Pb, Hg, Cd, and As were 198 µg/kg, 303 µg/kg, 75 µg/kg, and 519 µg/kg, respectively, while the average levels of As and Pb were 11,111 µg/kg, and 3,518 µg/kg, respectively, in soil samples collected from abandoned mining sites. Food crops (cassava and plantain samples) grown in abandoned mining fields had elevated levels of Pb (602 µg/kg) and Hg (15.7 µg/kg). Based on our findings of widespread exposure, high concentrations, and potential health risks posed by these metals, proactive measures for the reclamation and remediation of affected land are needed to protect the environment and human lives in these previous mining communities.

Keywords: Mining, galamsey, food system, water, health risk, heavy metals, Ghana

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INTRODUCTION

The concern for environmental sustainability is growing rapidly on a global scale. This is the result of increasing anthropogenic activities such as unsustainable agriculture, construction, deforestation, industrialisation, mining and pesticide application. The mining industry represents one of the largest and most economically viable ventures in the world. The industry has gradually expanded its scope from conventional small-scale methods to large-scale mining [1]. In Ghana, most small-scale artisanal miners, known as 'galamseyers', are indigenous unemployed youngsters with no prior mining training or experience who engage in surface mining, often without a licence [2]. Ghana, formally known as the Gold Coast, is one of the world's top gold producers [3], and artisanal small-scale mining (ASM) is a significant source of gold production [4]. The mining industry contributes significantly to the country's gross foreign exchange earnings [5]. At the same time, the sector has become a major contributor to environmental degradation and a major source of pollution due to the proliferation of indiscriminate mining activities [6]. Pollution from artisanal small-scale mining activities creates a significant pollution burden on local communities due to proximity to mining and may be associated with increased adverse impacts on food, water and vegetation in communities.

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Among the several harmful impacts associated with the mining industry, exposure to potentially toxic elements has been of great concern. This is a result of the release of metals and metalloids from the earth's crust during mining operations, as well as the use of metals such as mercury during processing. The release of these potentially harmful metals from mining areas has been associated with adverse human and environmental health outcomes. While metals such as copper, zinc and manganese are necessary for various metabolic processes, they can be toxic in large doses. On the other hand, elements such as cadmium, arsenic, lead, and mercury have no known role in the body and are toxic even at low concentrations [7]. In general, toxic metals pose a growing threat to ecosystems and human health due to their ability to persist, bioaccumulate, and biomagnify over time, with potentially devastating impacts [8,9]. For example, studies show that years after their active service, small-scale mines can continue to be a significant contributor to heavy metal contamination in the environment [10].

Furthermore, due to the limited land for agricultural purposes, mining communities tend to use abandoned mined land for agricultural activities, often without the necessary reclamation measures. Within such abandoned mining communities, heavy metal exposure may occur through various routes such as dust inhalation, direct ingestion, dermal contact, and the consumption of crops cultivated on these abandoned mining lands [11]. The results of several studies in Ghana and elsewhere point to the significant contribution of mining activities to heavy metal exposure. Akoto et al. (2023) reported that heavy metals Hg, Pb, As, Cd, Cr and Fe were present in higher concentrations in the top soils of a mining town in the Northern region of Ghana compared to a control site [12]. Similar findings have been reported at various locations in southern Ghana [13,14]. Mining activities have also been shown to have significant impacts on water bodies, including rivers and sediments [14,15,16], as well as vegetation and crops [17,18]. In general, mining activities are found to play an important role in the exposure and transport of metal contaminants in the environment [19,20]. In recent years, concerns about the scale of destruction associated with ASM operations in Ghana, such as deterioration of water quality, destruction of forests and farms, and severe land degradation, have led to public outcry and a subsequent ban on artisanal-scale mining activities. Although the enforcement of the ban remains a challenge, the potential adverse impacts of exposure to potentially toxic metals through the consumption of water, food and environmental interaction within mining communities remain high. Evidence from the literature points to elevated levels of heavy metals in active mining communities [21,22]. However, there is limited knowledge about the levels, exposure, and impact of heavy metals from previous mining communities.

This study provides knowledge on the levels of heavy metals in food, water, vegetation, and soil samples from previous mining communities and estimates the health impacts of exposure in these communities. The results obtained were compared to those of the Food and Agriculture Organization and World Health Organization (FAO/WHO) standards.

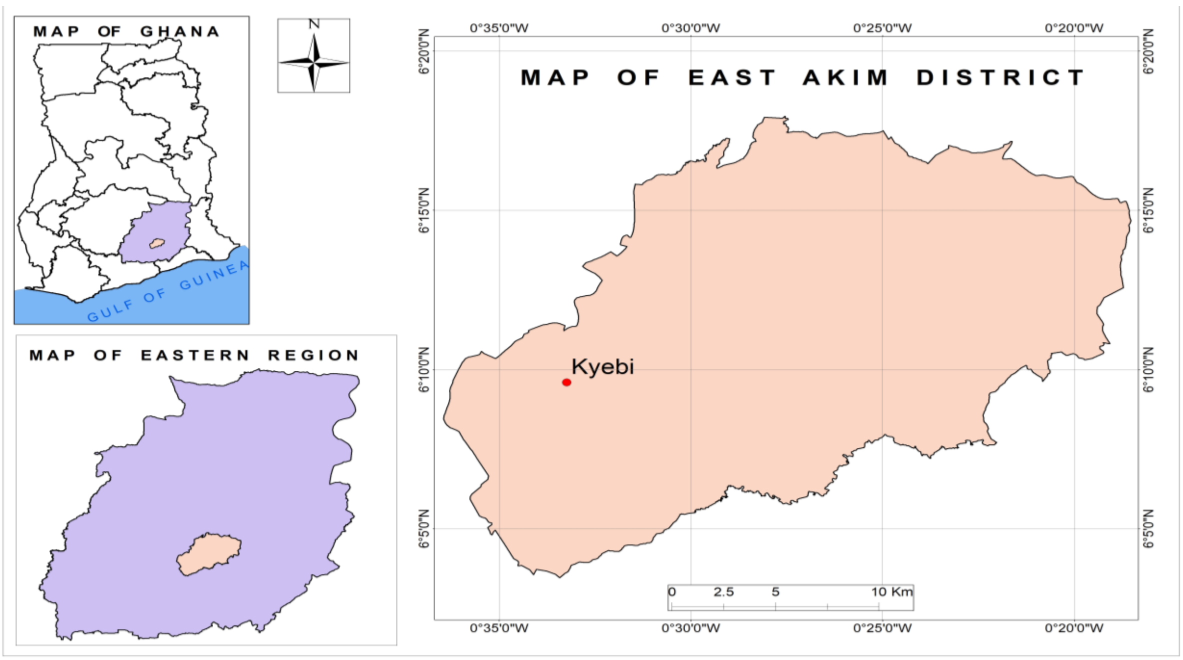

Figure 1. A map showing the sampling town in the eastern region of Ghana (Author's drawings)

MATERIALS AND METHODS

Geographical description of the sampling area

The sampling area is located in Kyebi, the administrative capital of the East Akim Municipality in the Eastern Region of Ghana (Figure 1). The municipality is situated within the moist semi-deciduous forest region of the country. The area encompasses forest reserves covering approximately 108.8 square kilometres, including a part of the Atiwa forest reserve [23]. The area is reported to contain granite rocks that contain several mineral deposits, including gold, diamond, and bauxite [24]. Soils in the area are known to be suitable for the cultivation of cash crops, including cocoa, coffee, palm oil, and cola, as well as food crops such as cassava, plantain, yam, and maise.

Sampling and preparation of samples

Samples of soil, cassava, plantain, turkey berry fruits (*Solanum torvum*), and *Chromalaena odorata* (locally called acheampong) leaves were collected from various abandoned mine sites in up to five different communities of the town. In all communities visited, mining sites were reported to have ended for at least ten years. Labelling was done according to the sites visited for easy identification. Soil samples were obtained from at least five different sites where mining had previously been carried out. All soil samples were obtained from shallow pits at different mining sites. At each location, six to ten samples were obtained, and a composite sample was formed from the individual samples. The samples were collected in clean polyethylene bags, sealed, and sent to the laboratory for sample preparation and analysis. Cassava and plantain samples were obtained from three communities. The samples were peeled and cut into smaller pieces to ensure faster air drying. Vegetation samples were obtained from the five communities visited. In all communities, three to five plant samples were obtained, and a composite sample was prepared for each community. The soils, *Solanum torvum* fruits, and *Chromalaena odorata* leaves were air-dried for two weeks. The soil samples were sieved using a 150-micrometre sieve. All other samples were pulverised using a stainless steel blender prior to digestion. Where available, control samples were obtained several kilometres (≥10 km) from abandoned mining sites for comparison.

Microwave digestion

Approximately 1.0 g of each sample was accurately weighed using an analytical balance (KERN PLJ). The samples were then placed in microwave digester vessels (Milestone ETHOS UP) and digested with 5 mL of HNO3 and 3 mL of H_2O_2. The microwave digester was operated using the following parameters: a temperature of 170 °C, a power of 1000 watts and a pressure of 50 bar for a total duration of 50 minutes (split into two runs of 25 minutes each). The samples were digested for one hour and allowed to cool. The digest was quantitatively transferred into graduated centrifuge tubes and diluted to the 25 mL mark with deionised water after washing the walls of the vessel. The 25 mL solution was transferred and stored in sample bottles for analysis.

ICP-MS analysis

Heavy metal concentrations of Hg, Pb, Cr, Co, Mn, Zn, As, Cd, Co, Ni, and Fe were determined using an inductively coupled plasma mass spectrometer, ICP-MS (Agilent 7700 series) equipped with MassHunter Workstation software. The ICP-MS device was calibrated with standards for all relevant metals of interest prior to the analysis of the samples. The results of the metal analysis were corrected using reagent blanks.

Reagents

All reagents and chemicals used were of analytical grade. Concentrated HNO_3 (65%) and H_2O_2 (30%) were obtained from Merck (Darmstadt, Germany). A multielement standard solution comprising all relevant metals was procured from VWR Chemicals (Belgium). Standard solutions were prepared from the 100 mg / L stock standard in 2% HNO_3. Calibration standard solutions were prepared from the stock multielement standard by serial dilution.

Quality assurance

Sample bottles and glassware used were cleaned with metal-free detergent and thoroughly rinsed with deionised water. The glassware was soaked in 10% HNO_3 for about 24 hours to remove metal particles that adhere to the glass surface. Distilled water was used in the preparation of all the solutions and stored in a capped plastic bottle. Blank solutions were prepared using distilled water, chemicals, and reagents to digest the samples. ICP-MS readings of the samples were corrected by using the results of the analysis of the blanks.

RESULTS AND DISCUSSION

The concentrations of 11 metals in the various sample types are reported in Tables 1-4. The findings show a wide range of concentrations among the various metals and samples from within the various communities and mining sites. The water samples from within the communities consisted of three main types: river water, groundwater/borehole water, and packaged water (sachet / bottled). The pH of the water samples ranged from 5.71 – 7.48, with a mean value of 6.57 (SD 0.65), reflecting the slightly acidic conditions of the water within the communities. Similar findings have been reported [25,26]. Wells constitute the predominant source of water in the communities studied. On the contrary, the river water appeared to be of lower quality on visual inspection, largely due to apparent high turbidity. In this study, river water samples recorded the highest pH value of 7.48.

Heavy metals in water

The levels of metals in water were generally lower than the levels in food, vegetation, and soils. This is expected given the generally protected nature of the water samples evident in boreholes. As expected, Mn and Fe showed the highest concentrations in the water samples, reflecting their general abundance in nature. Fe concentration ranged from 2.07 - 721 µg/L with an average value of 207 (SD 10 µg/L). More importantly, the highest value of Fe was observed in river water, possibly influenced by mining activities within communities. This value, as well as two (2) of the borehole samples, exceeded the accepted value of Fe in drinking water based on WHO and the United States Environmental Protection Agency (USEPA) standards. However, the concentrations in this study are generally lower than those reported in the water of active mining sites [25,27]. The lower values reported may reflect the protection provided by underground/boreholes, as well as differences in active mining activities at the time of sampling. The Mn concentration ranged from 158.2 - 339 µg/L with an average of 237 (SD 10 µg/L). These values are all above the WHO (100 µg/L) and USEPA (50 µg/L) recommended limits for drinking water. These findings agree with reports of similar studies conducted in the Tarkwa metropolis in borehole water [28]. However, Bempah and Ewusi et al. (2016) reported lower levels of Mn in drinking water (98.45 - 143.26) than those recorded in this study [29]. Although Mn is a natural constituent of groundwater, elevated levels of Mn can be attributed to its increased exposure to the environment through activities such as mineral mining in the communities studied.

Furthermore, Fe and Mn have been reported to have key associations with gold-bearing rocks mined in Ghana, possibly explaining their abundance in study communities. The levels of Cr, Co, Cu, Ni, and Pb ranged from 0.010 – 6.6 µg/L, 1.95 – 7.8 µg/L, 1.03 – 13.3 µg/L, 0.60 – 9.5 µg/L and 2.0 – 6.6 µg/L respectively. The concentrations of Cr, Co, Cu Ni, and Pb were below the allowable limit of WHO and USEPA for drinking water, likely reflecting their low natural levels in the environment. Similarly, Cd and Hg levels were below detection limits in almost all samples. In general, the concentrations of metals in the water samples varied in the order Mn>Fe>Cu>Pb>Cr>Ni>Co>Cd>Hg and were largely influenced by the source of water and its exposure to mining activities, underbearing rocks, and pH of the waterbody [30,31]. pH is vital in the nature and mobility of metal elements in water. Given this, the slightly acidic nature of the water samples may have contributed to the levels reported in this study.

Heavy metals in vegetation

The choice of *Solanum torvum* and *Chromolaena odorata* was due to their abundance in almost all the sites studied. These two plants were found to grow wild in almost all abandoned mining sites visited. Metal concentrations (µg/kg) of metals in *Solanum torvum* ranged from 6,515 – 9,732 for Zn, 6.42 – 22.41 for Pb, 2.07 – 6.19 for Hg, 10,610 – 15,529 for Cu, 234.6 – 937.8 for Cr, 2.11 – 4.18 for Cd and 19.42 – 62.1 for As. Similarly, mean *Chromolaena odorata* concentrations ranged from 8,045 to 14,620 for Zn, 125.44 to 254.2 for Pb, 114.6 to 491.7 for Hg, 13, 837 to 20,732 for Cu, 968.3 to 2196 for Cr, 52.9 to 86.3 for Cd and 230.4 – 711.9 for As. In both sets of samples, the levels of Zn, Cu, Hg, and Cr exceeded the WHO-recommended limits. More importantly, the control samples from the communities had significantly high levels of these metals, reflecting the generally elevated levels of potentially toxic metals in the communities studied. It is likely that elevated levels may reflect the higher ability of these plants to accumulate these metals. The high levels in *Solanum torvum* are of great concern given their use as an important vegetable, particularly among nursing mothers, mainly as a source of iron. The findings of these two plants provide an indication that the vegetation within these communities may contain elevated levels of metals, possibly at potentially toxic levels. This portends considerable environmental risks, given their possible exposure to plants, crops, animals, and humans [32]. The results obtained in this study are generally lower than those reported in similar studies in other locations [33,34]. These results reflect the general persistence of metal exposure

Table 1. pH and mean concentration (µg/L) of heavy metals in different sources of water in communities

Sample	pH	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb
Packaged water-1	6.20 ±0.02	-	0.01 ±0.02	3.09 ±0.06	2.6 ±0.1	2.1 ±0.5	-	-	0.6 ±0.2	6.6 ± 0.2
Packaged water-2	5.71 ±0.08	-	0.052 ±0.007	1.95 ±0.07	7.1 ±0.2	2.1±0.1	-	-	0.7 ±0.2	2.0 ±0.1
River water	7.48 ±0.22	-	1.5 ±0.2	3.6 ±0.2	3.8 ±0.2	721 ±7	-	163 ±2	2.0 ±0.2	5.1 ±0.1
Borehole -1	6.72 ±0.12	-	6.6 ±0.2	4.8 ±0.2	4.63 ±0.07	14.6 ±0.4	-	223 ±10	9.5 ±0.4	3.48 ±0.07
Borehole -2	6.22 ±0.04	0.3 ±0.1	1.78 ±0.06	7.8 ±0.3	12.6 ±0.3	321 ±6	-	301 ±5	4.6 ±0.4	5.2 ±0.1
Borehole -3	6.31 ±0.05	-	0.9 ±0.1	2.8 ±0.3	13.3 ±0.3	145 ±2	-	158±10	3.3 ±0.1	2.07 ±0.07
Borehole -4	7.37 ±0.04	-	0.09 ±0.03	3.16 ±0.05	1.03 ±0.09	246 ±4	-	339 ±8	1.1±0.1	3.51 ±0.05
Mean	6.57 ±0.65	0.04 ±0.01	1.6±0.3	3.9±0.4	6.4±0.5	207±10	-	237 ±10	3.1±0.7	4.0 ±0.3
WHO Limit	6.5-9.5	3	-	50	2500	300	6	100	-	10
US EPA Limit	6.5-8.5	5	-	100	1300	300	2	50	70	15

Cd=cadmium, Co=cobalt, Cr-chromium, Cu=copper, Fe=iron, Hg=mercury, Mn=manganese, Ni=nickel, Pb=lead
WHO= World health Organization
US EPA= United State Environmental Protection Agency

through mining activities and their possible impact on ecosystems over time [10].

Levels of heavy metals in cassava and plantain samples
The mean concentrations (μg/kg) for Zn, Pb, Hg, Cu, Cr, Cd, and As in plantain fruit samples were 2,309.9 ± 0.8, 7.85 ± 0.04, 4.81 ± 0.09, 2721.1 ± 0.9, 7.9 ± 0.2, 0.74 ± 0.02 and 2.74 ± 0.02, respectively. The results of these metals in the plantain peels were significantly higher than in the fruits. Nonetheless, the findings from both sets of plantain samples revealed values within the acceptable limits. Similar studies carried out in food samples generally presented higher values for Zn, Pb, Cu, Cr, and Cd than those obtained in this study [34]. The mean concentrations (μg/kg) of metals in cassava samples were 7179 for Zn, 602 for Pb, 3.2 for Hg, 784 for Cu, 36 for Cr, 8.1 for Cd, and

Table 2. Mean concentration (μg/Kg) of heavy metals in vegetation

Sample	Zn	Pb	Hg	Cu	Cr	Cd	As
Turkey berry (Control)	5811±30	8.7±0.8	1.4±0.2	9203±30	108±10	2.09±0.03	11.8±1.2
Turkey berry -1	9732±20	22.4±0.4	2.2±0.8	15529±40	235±20	3.25±0.02	19.4±1.5
Turkey berry -2	6515±32	19.5±0.7	6.2±0.8	10610±32	938±100	4.18±0.08	62.1±3.0
Turkey berry -3	7985±34	6.4±0.5	2.1±0.9	11972±41	330±30	2.11±0.06	26.3±2.2
Average value	8077±1600	16.1±8.5	3.5±2.3	12704±2500	501±380	3.2±1.0	36±22
Chromolaena odorata (Control)	19784±70	133±10	8.2±2.6	12293±70	1095±30	18.6±6.0	104.6±2.2
Chromolaena odorata-1	14620±30	254±90	492±80	16006±30	2196±60	84.2±20	711.9±9.4
Chromolaena odorata-2	13535±30	125±80	115±40	20732±60	968±10	86.3±20	230.4±30.3
Chromolaena odorata-3	8045±20	215±90	303±20	13837±60	1520±50	52.9±10	614.6±14.0
Average value	12067±3500	198±70	303±190	16858±3500	1561.5±620	75±20	519±250
WHO Limit	5000	300	10	10000	300	200	-

Cd - cadmium, Cr - chromium, Cu - copper, Hg - mercury, Mn - manganese, Pb - lead, Zn - zinc
WHO -World health Organization

Table 3. The mean concentration (μg/Kg) of heavy metals in cassava and plantain samples

Sample name	Zn	Pb	Hg	Cu	Cr	Cd	As
Plantains	2,310±80	7.9±1.4	4.81±2.0	2721±90	7.9±2.0	0.74±0.20	2.74±0.22
Plantain Peels	8196±100	67.8±8.0	4.2±1.0	12845±200	151±20	2.69±0.60	37.9±7.0
Cassava	7179±190	602±180	3.2±1.0	784±160	36±8	8.1±1.0	BDL
Cassava Peels	10,529±200	295±60	15.7±10	2586.±30	1657±40	12.9±0.8	221±40
Cassava (Control)	3220±90	42±10	0.4±0.1	1223±100	BDL	6.5±1.0	BDL
FAO/WHO Limits	50000	300	-	30000	20000	2000	-

Cd-cadmium, Cr-chromium, Cu-copper, Hg-mercury, Mn-manganese, Pb-lead, Zn-zinc
WHO - World health Organization
FAO - Food and Agriculture Organization

Table 4. The mean concentration (μg/Kg) of heavy metals in soils from five communities

Sample Name	Zn	Pb	Hg	Cu	Cr	Cd	As
Soil Sample-1	6885±100	3232±200	8.04±0.07	10640±400	16301±400	7.54±0.40	13049±100
Soil Sample-2	9634±200	5670±200	20.7±0.6	19298±500	28078±700	15.54±0.40	15608±300
Soil Sample-3	1497±80	2346±120	13.4±0.1	3604±200	8069±200	5.08±0.40	5184±800
Soil Sample-4	2678±100	3109±600	9.02±0.08	7192±100	15561±300	8.02±0.60	11128±100
Soil Sample-5	2925±700	3234±900	9.23±0.05	6944± 200	15512±300	9.87±0.28	10586±200
Soil (Mean)	4,724±3400	3,518±1300	12.1±5.3	9,536±6000	16,704±7200	9.2±3.9	11,111±3900
Control Soil	2206±60	1795±60	12.4±1.0	1183±300	1899±90	6.26±0.50	185.3±0.3
FAO/WHO Limit	50,000	10,000	300	20,000	30,000	60	30000

Cd-cadmium, Cr-chromium, Cu-copper, Hg-mercury, Mn-manganese, Pb-lead, Zn-zinc
WHO - World health Organization
FAO - Food and Agriculture Organization

below the detection limit for As. The recorded levels were within the FAO/WHO set limits for cassava. Similar studies of active mining sites have reported higher levels of several metals [34], including Hg in cassava [35]. Comparatively, cassava peels recorded significantly higher levels of almost all metals compared to cassava stock. The mean concentrations of metals in plantain were generally higher than those in cassava samples for almost all metals. This may be due to the general accumulation of metals in the parts of the food crop compared to the parts of the roots [36]. For all metals, the concentrations in the cassava and plantain peels were higher than recorded in the stock of each crop. This suggests the preferential accumulation of metals in the peels and husks of plantain and cassava, a trend reported in the literature for several crops [37,38]. Although this phenomenon presents huge environmental risks since peels are used in manure or as feed by animals, the accumulation of peels helps to reduce the levels of metals in edible parts, helping to reduce their direct health risk from consumption in humans.

Levels of heavy metals in soil

Metal levels were generally high in the soils of all communities sampled. Cr showed the highest levels (µg/kg) in soil samples with a range of 8,069 – 28,078 in all studied sites with a mean value of 16,704 (SD 7200 µg/kg). These values are seen as significantly high, particularly for the West African region, where metal levels are generally lower compared to the Asia/Latin American regions. However, even higher values of up to 110000 µg/kg and 739,500 µg/kg have been reported by Botwe et al. (2020) and Akoto et al. (2016), respectively, from active mining sites [39,40]. Hg recorded the lowest levels in soil samples studied with a range of 8.04 – 13.4 µg/kg and an average value of 12.1 (SD 5.3 µg/kg). Similar values (0.7 – 8 µg/kg) have been reported in the Wassa West District of the Western Region of Ghana [41]. However, significantly higher concentrations (220 – 1,750 µg/kg) have been reported in soil samples from the main mining town of Obuasi in the Ashanti region of Ghana [29]. Although Hg is found in the earth's crust and may be exposed through mining activities, elevated levels of the metal at Ghana's mining sites are mainly due to its use during gold processing from its ore. This activity is despite the commitment of Ghana as a signatory to the Minamato Convention on curbing the proliferation of mercury use in the environment. Given the nature of its use in small-scale mining in Ghana, Hg can largely evaporate from mining sites and spread to nearby communities [42].

The concentration of Zn ranged from 1497 to 9634 µg/kg with a mean of 4,724 (SD 3,400 µg/kg). These results are significantly lower than those reported by Gyamfi et al. of 16,400 – 95,800 µg/kg [25], Adomako et al. (14,400 – 98,300 µg/kg) and Tibu et al. (30,160 – 39,630 µg/kg) [43,44]. Generally, higher levels of Cu were recorded in soils with values ranging from 3,604 to 19,298 µg/kg with an average value of 9,536 (SD 6,000 µg/kg). Similar to other metals, these values are generally lower than similar studies from active mining sites reported [10,33,45]. As expected, the results of the highly toxic metals Pb, Cd, and As were relatively low, with values ranging from 2,346 to 5,670 µg/kg for Pb, 5.08 to 15.54 µg/kg for Cd, 5,184 to 15,608 µg/kg, respectively. As similarly observed for other metals, the concentrations recorded in this study are generally lower for some metals than those reported in other studies [46,47]. The mean concentrations of Zn, Pb, Hg, Cu, Cr, Cd, and As in the soils sampled from all abandoned mining sites were considerably higher than those obtained at the control site within the community at least 10 km from any known active site. This finding suggests that mining activities in communities have contributed to the exposure to metals and the elevated contribution. Although the concentrations were generally within suggested limits, elevated levels present significant risks to the ecosystem given that, in some cases, soils were obtained from sites that had experienced mining activities more than a decade ago. Even more significant is the exposure of metals to humans through uptake by vegetation and crops [48]. Generally, the findings of this work affirm that mining activities may have a lasting contribution to the exposure of toxic metals or metals at potentially toxic levels even years after the cessation of mining. This adverse effect may occur from exposure to metals through vegetation and uptake by crops, consumption of water and inhalation, and dermal contact through the high mobility of these metals in the environment once exposed. By their nature, the non-biodegradability of metals makes their exposure through indiscriminate mining activities a serious and persistent source of concern. However, the findings of the study are limited by the availability of abandoned sites and relevant crops and vegetation at these sites.

Conclusion

The findings from the study show the significant influence of mining on the exposure of metals in water, vegetation, crops, and soils. Compared to control samples, almost all metals studied (Zn, Pb, Hg, Cu, Cr, Cd, and As) recorded higher levels in crops, water, vegetation, and soils from abandoned mining sites and communities compared to controls or recommended limits. The study suggests that although previous mining sites and excavated soils from previous mining activities may have lower concentrations of metals, they continue to contribute to the exposure of metals in the ecosystem, particularly through their absorption in plants. These findings present considerable risks of toxicity to humans, given that, once exposed, metals do not biodegrade but become more mobile in the ecosystem with increased exposure to humans. Given the proximity of small-scale artisanal mining to human settlements, the indiscriminate mining activities and processes, and the use of toxic metals such as mercury in mining operations, the risk posed by mining activities is considerable during the life of the mining operations. Unfortunately, these risks may persist for many years, posing huge detrimental risks to humans. As a result, proper enforcement of mining restrictions and regulations is imperative. This, along with the proper restoration of previous mining sites, will be needed to minimise human risk and protect lives in many communities in Ghana, considering the proliferation of active mining activities throughout the country.

DECLARATIONS

Ethical consideration

There were no significant ethical risks from this study. Ethics approval was obtained from the Noguchi Memorial Institute for Medical Research Institutional Review Board (Protocol# 048/17-18)

Consent to publish

All authors agreed on the content of the final paper.

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Competing Interest

None

Author contributions

The study was conceived by RA and Designed by AKC and ED. RBO, AKC and ED collected data. Analysis and data processing was led by ED and RBO. The manuscript was drafted by RBO and ED and approved by all authors.

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Availability of data

The data for this work is available upon request from the corresponding author.

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