



Concentrations and human health risk assessment of selected heavy metals in soils and food crops around Osukuru phosphate mine, Tororo District, Uganda

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ABSTRACT

This study investigated the concentrations of heavy metals, particularly chromium (Cr), cadmium (Cd); lead (Pb), copper (Cu), and iron (Fe) in the soil and crops. The accumulation of heavy metals in the crop system, the probable daily intake of heavy metals, and the assessment of potential health threats associated with the uptake of metals by the residents around the Osukuru phosphate mine in Tororo, Uganda. The concentrations were assessed with the assistance of an Atomic Absorption Spectrometer (AAS). The crops studied were amaranthus (*Amaranthus hybridus*) leaves, pumpkin (*Cucurbita pepo*) leaves, maize (*Zea mays*) grains, and cowpeas (*Vigna unguiculata*) leaves. A total of 200 samples were collected from five villages of Osukuru Sub County. The findings of this study showed that elemental concentrations of heavy metals in the soil were within the standard recognized limit for agriculture as documented by World Health Organization (WHO) and European Union (EU). While more noticeable levels of these elements were detected in crop samples, especially amaranthus. Chromium composition was lower than the detection level in all samples. The transfer factor results showed elemental intake by the crops in the sequence; Fe > Cu > Cd > Pb. The probable daily intakes of the elements were below the daily threshold values endorsed by WHO/FAO. The health threat index showed high values for Pb and Cd from maize but low values of Cu and Fe in all samples and therefore these crops may not be very safe for human intake.

1. Introduction

Chemical elements like lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), arsenide (As), mercury (Hg), and nickel (Ni) among others are known to have high atomic density and therefore regarded as heavy metals. These elements have existed in soils since its creation and are thus considered natural components of the soil [1]. Natural elemental compositions in the soils have been reported to be non-poisonous until when their concentrations are enhanced and reach a certain maximum permissible level. Heavy metals with high concentrations can lead to increased environmental pollution and consequently dangerous health effects on humans [2].

However, elements like Cu, Zn, Fe, Ni, and Mn are required for plants and animals' biochemical and physiological functions. On the other hand, Pb, Cd, Hg, and As are some of the metal elements that are not required by plants and animals for any biological function [2,3]. These metal elements (Pb, Cd, Hg, and As) are poisonous even at low

concentration levels. Daily, heavy metals accumulate in vital organs of the human body like the kidney, lungs, brain, and liver, among others [4]. At the moment there is no established mechanism for eliminating heavy metals from the body, thereby leading to serious health consequences such as kidney failure, joint weakness, memory loss, etc. [5]. Heavy metals can be introduced into the soils and environment from the rapid expanding commercial regions, mining and processing sports, atmospheric deposition, dumping of harmful industrial metallic and mineral wastes, leaded gasoline, farm application of phosphate fertilizers and animal manures, among others [6].

These metallic elements from the soils accumulate in plants including food crops such as leafy vegetables and yet vegetables are consumed widely by many households globally. This is because vegetables are regarded to be the main sources of minerals, fibers and vitamins essential for human physiology [7]. According to Singh et al. [8], plants can get polluted by absorbing metallic elements from polluted air, soil, and water. Once cultivated on contaminated soils, leafy vegetables

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such as, amaranthus and pumpkin leaves accumulate elevated amounts of metal elements in different parts of the plant [9].

Human beings are internally and externally exposed to heavy metals due to ingesting crops grown on fertilized and unfertilized soils and inhaling rock and fertilizer dust [10]. The soil–plant–man transfer factor is a broadly used parameter to estimate heavy metal intake ingestion [9]. According to a study done by Leitner et al. [11], it is reported that extreme concentrations of heavy metals in food crops are dangerous to human health as some of them are regarded to be a prime cause of different styles of cancer in human beings. Thus, the transfer of heavy metals from the rock phosphate to the biosphere turns into a crucial study putting into attention their presence, endurance, and effects on the natural surroundings along with people [12]. It has been reported that the Eastern part of Uganda has been found to have numerous minerals that permit mining. Particularly, it has been indicated that Osukuru hills have phosphate mineral and rare earth metals that attracts utilization [13].

Studies have indicated that during mining, quarrying, and processing activities of minerals including phosphate, heavy metals concentration levels are enhanced in the environment, into the final products and byproducts [14]. These byproducts are regularly discarded in huge quantities and exposed to weathering and erosion. The byproducts thus occupy considerable ground areas which may result in severe environmental harm [15]. Consequently, human beings are exposed both internally and externally to varying concentrations of heavy metals [16]

from the environment. However, the information about the exposure of an individual resulting from these activities (mining, milling, etc.) and consumption of crops grown near the phosphate mines is scarce. This situation is also true for Uganda since there is no pre-operational baseline data on the environmental heavy metals concentrations around the Osukuru phosphate mines. This makes it difficult to evaluate the health implications once the mining operations have commenced. In this study, therefore, the Osukuru phosphate mine was chosen to provide baseline values of the heavy metals concentration levels in soil and crops around the mines and also to evaluate heavy metal transfer factor and their health risk to the residents of Osukuru Hills in Tororo district located in Eastern Uganda. Osukuru Hills is known to contain minerals such as phosphate and it is where phosphate mining and processing activities are taking place in Uganda.

2. Materials and methodology

2.1. Study area

This study was carried out around the Osukuru phosphate mine in the Osukuru Hills which is geographically located in Osukuru Sub County, Tororo District. Tororo District is positioned in Eastern Region of Uganda about 206 kilometers east of Kampala the capital city of Uganda. The place is also close to factories of Osukuru Industrial Complex which include a phosphate fertilizer factory, steel manufacturing

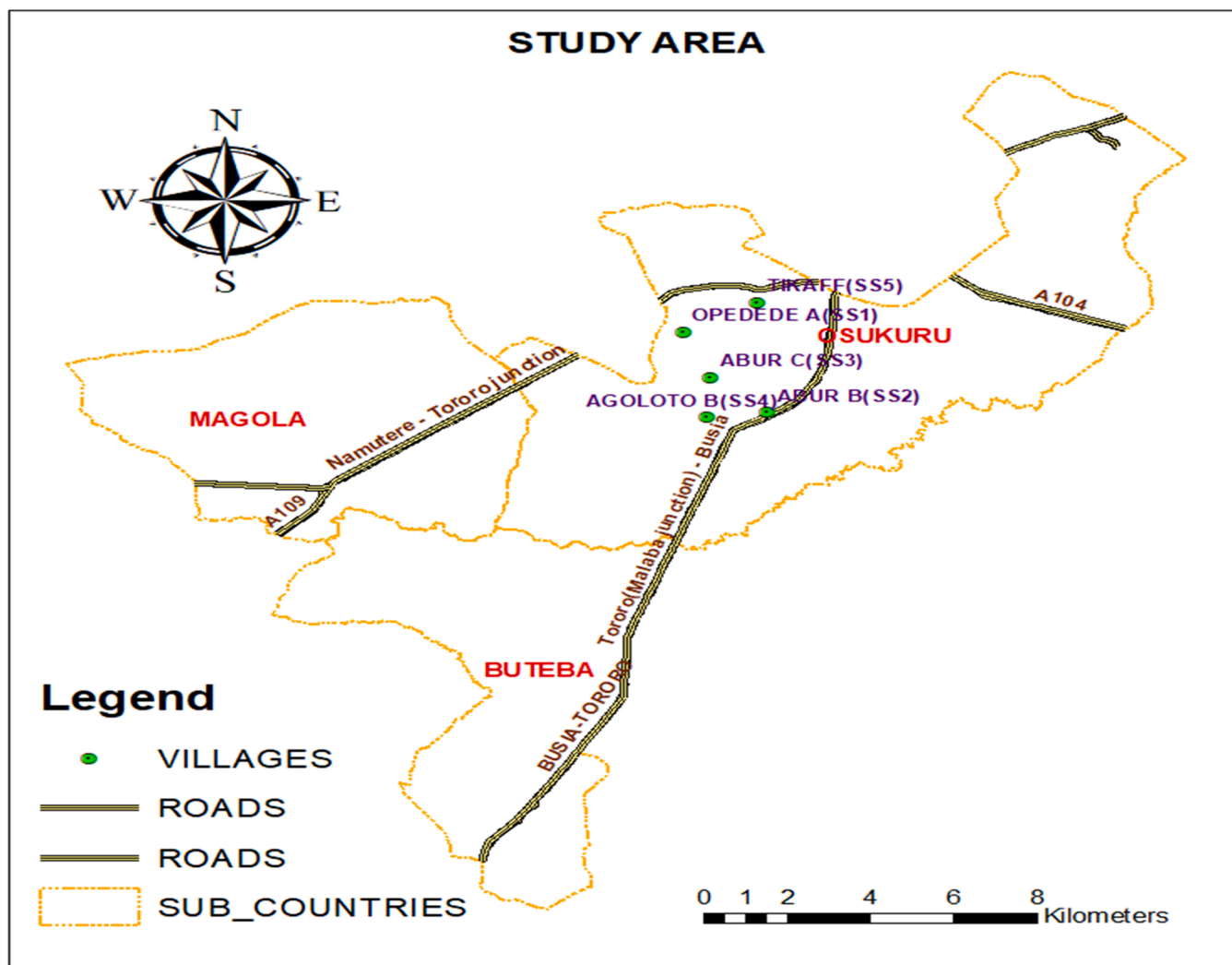


Fig. 1. Map of Osukuru showing study area and sample sites.

facility, sulfuric acid manufacturing factory, scarce earth metal mining plant, and Tororo cement factory. Fig. 1 indicates the map of the study location and sites where the samples were obtained.

2.2. Soil and crop samples collection and preparation

Sampling was carried out in the months of October and December 2021 in five villages; Opedede, Aburi B, Aburi C, Tikaff, and Agoloto B. These villages were chosen because they are close to the Osukuru phosphate mine and the processing plant as indicated in Fig. 1.

Depending on the agricultural activity of the area, in each of the five villages samples of crops and soils were randomly collected in the morning hours. The crop samples collected included vegetables (cowpeas, amaranthus, and pumpkin leaves) and maize grains. These particular crops were chosen for investigation since they are among the most grown and their leaves and flour (from the maize grains) are frequently eaten food crops by the residents. In each village, eight soil samples were collected together with eight samples of each corresponding crop. This is because at least eight gardens were found to have all the crops investigated. At every crop sample point, the soils were scooped using a spoon up to a depth of 15 cm where the roots of the crops normally grow so as to obtain reliable values of transfer factor.

A total of 200 samples were collected across the five villages. These included samples of soils, maize cobs, cowpeas leaves, pumpkin leaves, and amaranthus leaves from 8 different points for each village. Both the crops and soil samples were then packed separately in labeled polythene bags for transportation to the laboratory. The fresh crop samples were washed using tap water and rinsed with distilled water to remove the dust before being chopped into small pieces. Chopping into small pieces of the leafy part of the crops was done in order to facilitate drying at the same rate. The chopped crop samples were first dried in air for two days. This was done to ensure that the moisture is completely removed from the samples to avoid clumping of the samples during crushing. Then, the samples were grounded into powder by motor and pestle and sieved to obtain a homogeneous sample. From the 200 samples, 5 soil samples and 20 crop samples were obtained by mixing the identical samples from each village respectively. This was done by taking 10 g from each of the 8 soil samples from a particular village mixed together to make one representative sample from that village and placed in a labeled container. This procedure was repeated for all the other villages. The purpose of mixing the samples was to obtain a representative sample from each village in order to reduce the numbers of sample for easy sample handling and minimizing resources with regard to sample characterization. The packed and labeled containers were transported to the Uganda National Research Institute (UNRI) for analysis.

2.3. Sample digestion and characterization

The heavy metal concentrations were analyzed with the help of an Atomic Absorption Spectrometer (AA-Perkin Elmer 2005 USA) because it's good for detecting metal cations, especially those that are environmental pollutants. Prior to the use of AAS, the soil samples were heated in an electric hot air oven at 105 °C for 1 h and then removed and allowed to cool at room temperature. 5 g of each soil sample was weighed into a glass stoppered bottle and 20 ml of extracting solution (0.05NHCl + 0.025 H₂SO₄) was added into each sample bottle to extract the metals. The mixtures were then shaken for 15 min using an orbital shaker and filtered using a Whatman filter paper into a 50 ml volumetric flask and topped up to the mark using double distilled water. All the prepared samples were transferred into well-labeled sample tubes.

On the other hand, 3 g of each crop powder sample was weighed into a conditioned crucible for heating and the carbon was burned off using a hot plate to eliminate the organic matter. Each sample was then transferred to the muffle furnace and the temperature was set at 550 °C for 6 h to obtain the ash sample of each crop. The furnace was left to run for the set time until the temperatures dropped to 130 °C. The ash of each

sample was removed, placed into a desiccator for controlled cooling. The ash was used for easy dissolution in the nitric acid and distilled water.

The ash of each crop sample was dissolved using 1:1 Nitric acid (1 ml of concentrated nitric acid: 1 ml of distilled water) and filtered into a 50 ml volumetric flask and topped up to the mark using double distilled water. The samples were transferred into well-labeled sample tubes.

The decomposed soil and crop samples were then analyzed for heavy metals (Cd, Cr, Cu, Fe, and Pb) concentrations using Atomic Absorption Spectrophotometer (AA-Perkin Elmer 2005 USA) model available at the Uganda National Research Institute. All metal compositions were recorded in mg/kg. The limit of detection (LOD) for Cd, Cr, Cu, Fe, and Pb were 0.03, 0.04, 0.024, 0.06, and 0.05 g/ml respectively. This is an indication that the instrument used was in good sensitivity for the analysis.

2.4. Transfer factor of a metal element from soil to crops (TF)

The mobility factor of an individual metal element from the soil to the crop is the concentration ratio used mathematically to express the uptake of the metallic element from the soil by the crop. It is defined as the ratio of the composition of an element in the edible part of the crop (mg/kg) to the composition of an element in the soil (mg/kg) [17]. It was used to evaluate the impact of routine or accidental release of heavy metals into the environment. This factor is vital for environmental assessment by predicting the composition of the elements in food crops as well as establishing the dose intake by humans [18]. In this study, the transfer factor was determined from Eq. (1) [17], [19].

$$TF = \frac{\text{composition of element in crop sample}}{\text{composition of element in soil}} \quad (1)$$

2.5. Probable Daily Element Intake (PDEI)

The everyday intake of metallic element (Cd, Cr, Cu, Fe, and Pb) was determined by multiplying the elemental concentration in crops and the quantity of the respective crop eaten. The DEI of metals was obtained from Eq. (2) [20].

$$DEI = \frac{C \times K \times I}{W} \quad (2)$$

In Eq. (2), C is the elemental concentration (mg/kg), K is the conversion factor (0.085), W is the mean adult body weight and I is the everyday food intake. Each day's consumption of vegetables is considered to be 98 g per adult individual per day for a mature person of 60 kg body weight while 350 g of maize was considered per individual per day as suggested by WHO [22,21].

2.6. Health threat index (HTI) and danger index (DI)

The health threat index (HTI) from the ingestion of polluted crops was anticipated as the ratio of each day's intake of metal elements to the reference oral dose (RfD) of each metallic element. The HTI value of this index should be less than unity in order for the associated population to be considered secure.

$$HTI = \frac{DEI}{RfD} \quad (3)$$

Reference oral Dose are 0.001, 0.04, 0.004 and 0.7 mg/kg/day for Cd, Cu, Pb and Fe respectively.

The danger index (DI) is an important indicator to facilitate the evaluation of the general possible health threat that can be stood by ingestion of more than one pollutant [9]. The DI was determined by integrating the possible health threat for each pollutant as shown in the following Eq. (4).

$$DI = \sum HTI_{Cd} + \sum HTI_{Cr} + \sum HTI_{Cu} + \sum HTI_{Fe} + \sum HTI_{Pb} \quad (4)$$

The value of the danger indicator is comparative to the degree toxicity of the metallic element ingested.

3. Results and discussion

3.1. Statistical analysis of the results

The standard errors were calculated about the mean metal concentration in all the samples and results revealed a close relationship of the values obtained in all the villages except for Fe which varied significantly from sample villages. The average concentrations of heavy metals in soil and crop samples are shown in Table 1. In this table also the range and errors of the data are indicated.

3.1.1. Heavy metal concentration in the soils

The concentration for each sample was measured for five elements (i.e. Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), and Lead (Pb)) and the results recorded for each village is indicated in Fig. 2. The outcome in Fig. 2 shows that the concentrations of heavy metals in the soil samples were generally very low for most of the villages, except for Opedede.

This indicates that heavy metal concentrations in the soil samples followed the order; Pb(26.00to29.01mg/kg) > Fe(0.8to5.38mg/kg) > Cd (3.42to3.54mg/kg) > Cu (0.31–1.00 mg/kg). The composition of Cd measured in all soil samples was higher than the restrictions set by EU [23]. The other elemental concentration in the soils were beneath the standard restriction limits set by WHO/FAO as indicated in Table 2 [24, 23]. The slightly elevated composition of Cd in the soil could be related to the erosions of phosphate waste from the factory and mines since as well as utility of phosphate fertilizers during agriculture [25].

3.1.2. Heavy metals concentrations in crop samples

The outcome in Fig. 2 also showed a higher concentration of all the detected heavy metals under investigation in crops than in the soils. This is because crops take up mineral elements from the soil and in the process absorb metal elements. Plants build up metal elements in their tissues to concentrations higher than that in the soil content (bio-accumulation of metals). The extent of the heavy metal accumulation in the plant tissues varies from plant to plant due to a number of factors. These factors are the age of the plant, biochemical role of the metal, and the plant species (transpiration rate of the plant and even the physiological functioning of the plant species like the secretion of transporters that aid transport of metals across membranes) [27]. Other factors include the organic matter content of the soil, human activity, and environmental pollution. Additionally, it is vital to notice that the whole mass of the plant is less than that of the soil, but, the full contents of particular nutrients are continually more in the soil [27].

Fig. 2 also shows that Fe had the highest concentration levels (5.99–192.10 mg/kg) in all the crop samples followed by Pb (35.21–50.24 mg/kg) and Cu (1.13–9.78 mg/kg) had the least concentration levels. The heavy metal concentration levels were higher in the crop leaves than in the maize grains. However, the concentration levels

of heavy metals in the leaves followed the order of; amaranthus > pumpkin > cowpeas. This is in line with the report by Agic et al. [28] which revealed that unique plant parts contain extraordinary heavy metal quantities and the maximum portions are in roots and leaves, while the least is in the fruits and seeds [29].

Fe that seems to have higher concentration levels in crop samples (192.1 mg/kg) (Fig. 2) actually has lower values than the permissible limits of 425 mg/kg, set by WHO in 2002 and EU in 2006.

However, not all these kind of crops are secure to enter the food chain for human beings as the outcome from this study indicate that they are contaminated by Cd and Pb. The standard average concentration levels of Cd (0.2 mg/kg) and Pb (0.3 mg/kg) respectively are the permissible restriction level of elemental composition in crops as in Table 2. The average elemental concentrations of Cd (5.75 mg/kg) and Pb (41.04 mg/kg) respectively observed in this study were higher than the permissible regulations set by WHO in 2002 and EU in 2006.

The higher composition of Cd in all crop samples can be attributed to the utility of phosphate fertilizers since Cd is present as an impurity in the phosphate fertilizer [6]. Cadmium needs to be regulated in both soils and crops because once it enters the body it affects the normal functioning of the kidney since it declines the performance of enzymes responsible for reabsorption of proteins in the kidney [27]. The highest concentration values of Pb in most of the samples may be due to the elemental deposition from the phosphate mining activities in the vicinity which can be associated with exposure of heavy metals in the mineral ore (i.e. Pb) due to disposal, contaminations from the heavy trucks transporting materials from the mine to the factory [16].

3.2. Transfer factor of individual heavy metal from soil to crops (TF)

Human beings and animals are continuously uncovered to heavy metals through eating food, thus soil-to-plant mobility factor of metallic elements becomes one of the major ways this can be possible. Using Eq. (1), the calculated mobility factor for Cd, Cu, Fe, and Pb are as shown in Fig. 3.

Fig. 3 shows that the TF for Fe appears to be higher at Agoloto B in Amaranthus leaves (169.64) followed by Pumpkin (125.5) and then Cowpeas leaves (96.9), with the least in maize (8.04). The second higher TF values occurs for Cu but in a decreasing order at Agoloto B (34.56) for Amaranthus, (31.30) for Pumpkin leaves, (20.84) for Cowpeas leaves and (10.04) for maize grains. Hence, the TF is higher for Fe and Cu and lower for Pb (1.28) and Cd (1.44) all in the maize samples.

The higher mobility value of Fe and Cu may be attributed to the sturdy bioaccumulation of metal elements by the crops. These elements are essential nutrients that are required for plant development such as chlorophyll formation, photosynthesis, respiration, and transpiration among others. Thus Fe and Cu are more mobile than other metal elements investigated. There was a close correlation between the transfer values for each crop in the five villages. The transfer factor was also observed to depend on the plant species as it can be witnessed that the order of transfer factor from highest was amaranthus > cowpeas > pumpkin leaves > maize.

Generally, the TF of metal elements was higher in leaves than grains

Table 1

Average concentration of heavy metals in soil and crop samples (N = 20) on dry weight all in (mg/kg).

Sample	Index	Cd	Cu	Fe	Pb
Soil	Mean ± S. E	3.46 ± 0.01	0.52 ± 0.08	2.98 ± 0.43	27.58 ± 0.28
	Range	3.42–3.54	0.23–1.00	0.8–5.38	26.00–29.01
Pumpkin leaves	Mean ± S. E	5.99 ± 0.04	5.85 ± 0.21	123.59 ± 9.39	40.97 ± 0.85
	Range	5.72–6.24	4.62–7.20	77.52–189.56	35.21–45.8
Maize grains	Mean ± S. E	5.74 ± 0.10	2.39 ± 0.24	9.39 ± 0.84	36.41 ± 0.96
	Range	5.04–6.12	1.13–3.62	5.99–14.25	30.46–41.6
Cow peas leaves	Mean ± S. E	5.58 ± 0.10	6.75 ± 0.44	107.80 ± 7.15	42.02 ± 0.73
	Range	5.07–6.02	5.21–9.78	70.03–140.48	38.80–47.11
Amaranthus leaves	Mean ± S. E	5.70 ± 0.07	11.74 ± 1.46	136.77 ± 8.75	45.04 ± 0.79
	Range	5.18–5.98	5.93–20.82	87.87–192.10	41.48–50.24

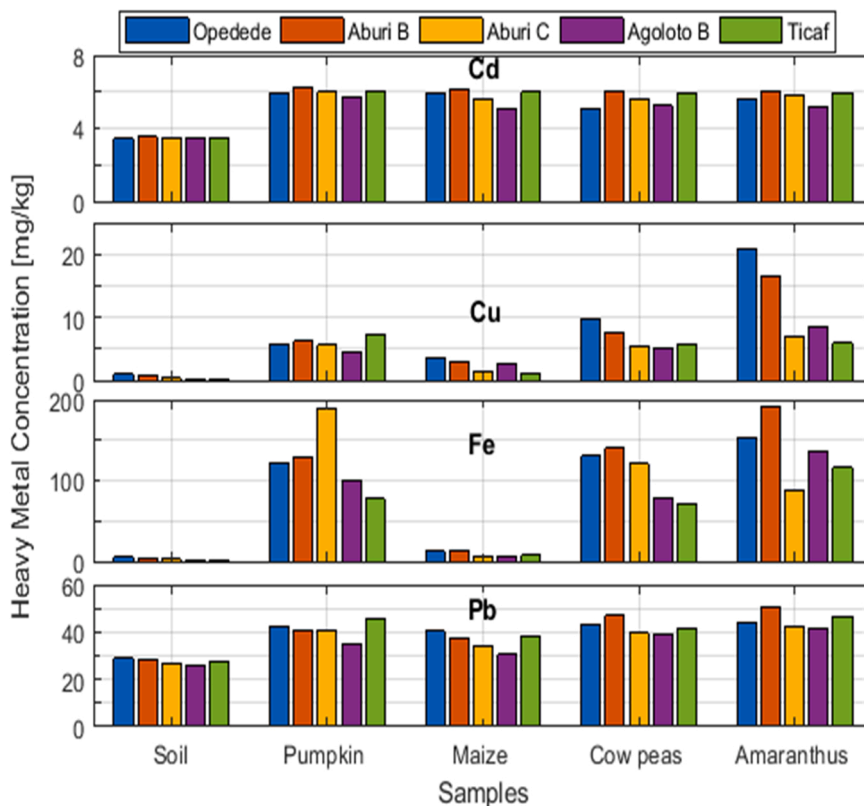


Fig. 2. Heavy metal concentration levels in soils and crops (mg/kg) from villages of Opedede, Aburi B, Aburi C, Agoloto B and Tikaf respectively.

Table 2
Maximum permissible values of heavy metals concentrations in soils and vegetables (mg/kg).

Standards	Sample	Cd	Cu	Fe	Pb
WHO/FAO [26]	Soils	5.0	73.3	–	100
	Vegetables	0.2	40.0	425	0.3
European Union [23]	Soils	3.0	140.0	–	300
	Vegetables	0.2	20.0	–	0.3

and varied with crop species and the age of the crop species. In addition, crop samples from crops that take a short period of time to be harvested and eaten were observed to have high TF, thus high metal composition [9,28]. The roots of these crops are almost on the surface and therefore take up heavy metals at a high rate even when the concentration of the metals are as a result of external factors such as erosion, dust, the utility of fertilizers, and cow dung [11].

It must be noted that a mobility factor of an element above unity is an indication of high metal element uptake by the crops. This can

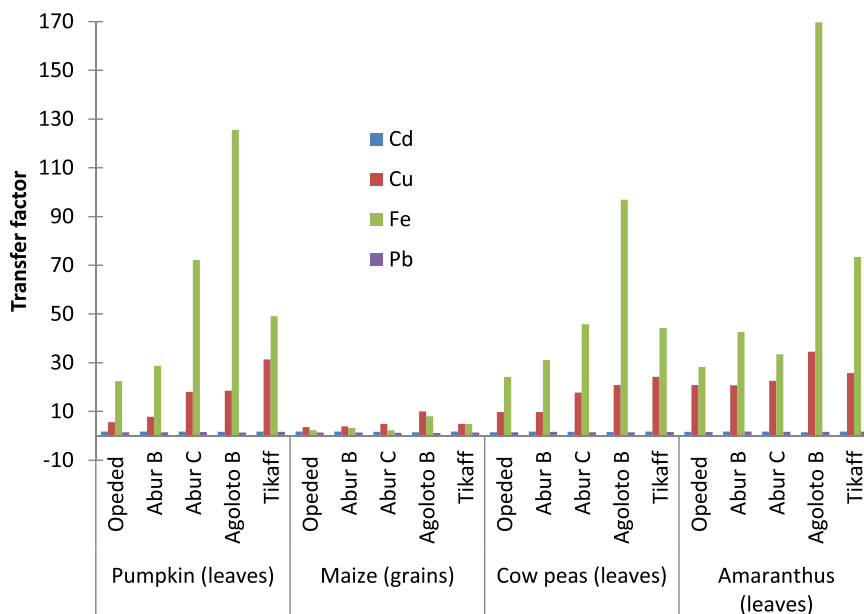


Fig. 3. Uptake of different heavy metals from the soil by the crops grown in the five villages.

significantly contaminate the food eaten by man hence leading to health complications. On other hand, a mobility factor less than unity describes the decline of crops to take in certain poisonous elements that can directly affect their rate of photosynthesis and stomatal conductance [30]. In other words, crops have the capability to absorb and decline the uptake of some metal elements and this capacity depends on the plant species and their adaptation to the environmental conditions.

3.3. Probable daily intake of metals (DIM)

The Probable each day intake of metal elements for a grown-up person was calculated using Eq. (2) and the outcome is depicted in Fig. 4. Each day metal elements consumption was high for Fe in amaranthus leaves (0.0269 mg/person/day) and pumpkins leaves (0.0265) followed by Pb in maize grains (0.0202) and lowest for Cu in pumpkin leaves (0.0006).

The intake of the metal elements (Cd, Cu, Pb and Fe) by man was taken to be through eating the food crops. All the day's intake of these metal elements was beneath the acceptable limit recommended by the WHO/FAO that is to say Pb (0.21 mg/person per day), Cu (2.0 mg/person per day), and Fe (15.0 mg/person per day) and Cd (0.21 mg/person per day). This implies that crops can be consumed but with great precautions and not frequently as the metals in them can bioaccumulate in the body tissues over time [4].

3.4. Health threat index (HTI) and danger index (DI)

Fig. 5 shows the impact level of heavy metals obtained by calculating the health threat index (HTI) and the Danger index (DI) using Eqs. (3) and (4) respectively. Food consumption is the major way human beings and animals are least protected from metallic elements. Fig. 5 shows that the HTI and DI values are high in maize grains for all villages. With exception of Pb where the HTI values are greater than unity for all the crop samples in all the villages, the HTI values for other metallic elements were less than unity.

This implies that residents of these villages are more likely to suffer from Pb poisoning as a consequence of eating crops polluted by Pb. The half-life of Pb is long and this makes it possible to move and accumulate in vital body organs like the brain, kidney, alimentary canal, and central nervous system thus leading to huge health complications in man. The most prominent complications attributed to Pb are chronic neurological

disorders, memory loss, loss of coordination, and paralysis [6,32]. Although the HTI values for Pb are above the acceptable limits tolerated for eating food crops, the outcome of this study is in agreement with Ikeda et al. [30] and Zhuang et al. [31] whose reports also revealed similar values for Cd and Pb that were above the permissible limits in vegetables and cereals. The probable DI values from eating the investigated crops were greater than unity (i.e. values ranged between 2.07 and 8.11). This indicates that crops grown around the Osukuru mine are not secure for man ingestion and present a health risk to the residents near the mine.

4. Conclusion

This study investigated heavy metals concentration levels in the soils and crops grown around the Osukuru phosphate mine. The findings from crops analysis for Cd, Cu, Fe and Pb indicated appreciable concentration levels of these metallic elements in all the samples. Chromium concentration levels were below the recognition limit in the soil and crop samples. The results also showed high heavy metal concentration levels in samples from Opedede, Aburi B, and to some extent in Tikaff village. Amaranthus leaves had the highest level of uptake of most of the heavy metals. This may be an indication of Amaranthus leaves having a higher bioaccumulation capacity than the other crops under investigation. However, in all cases, the concentration levels of these heavy metals were below the recognized limit for farming as set by FAO/WHO and EU. The study also revealed that the application of fertilizers may be a factor in enhancing the heavy metal concentration levels since gardens (crops and soils) where fertilizers had been applied were found to possess elevated concentration levels of heavy metals. Lastly, the Health index obtained from this study was found to be greater than unity, an indication of a potential health risk to the residents around the area due to the consumption of the crops grown around the Osukuru phosphate mine.

However, the results of this study did not consider the effect of soil pH, cation exchange capacity of the soils, and soil texture on the concentration levels of heavy metals since this was more of a preliminary study. More comprehensive testing is required to evaluate the influence of these soil parameters on the concentration levels and the crop uptake of various metallic elements in the different villages around the Osukuru phosphate mine.

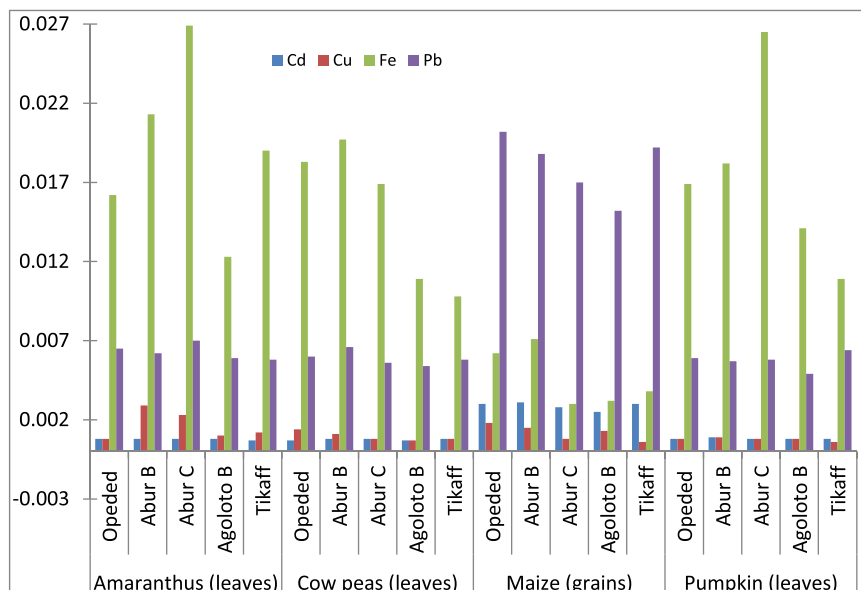


Fig. 4. Daily intake of different heavy metals from the consumption of the crops grown in the five villages.

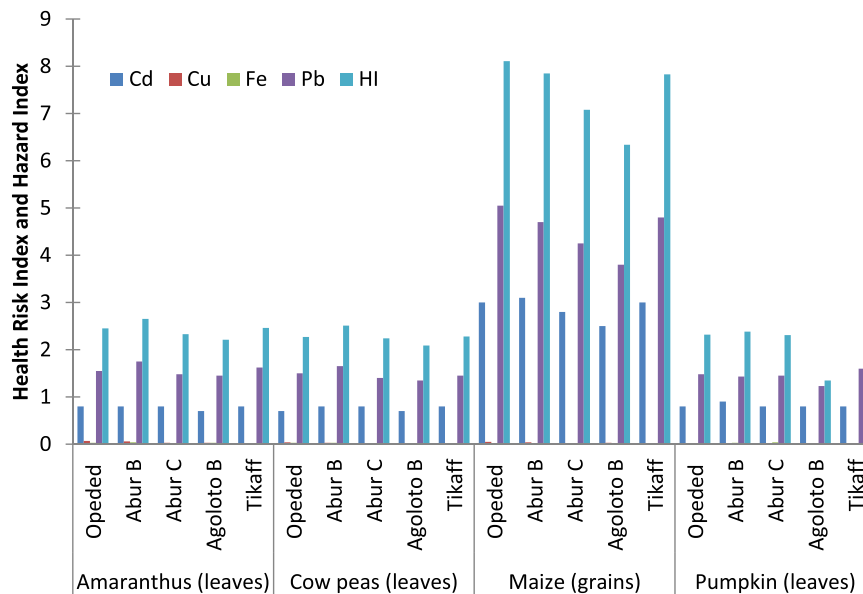


Fig. 5. Health threat index and hazard indices due to the consumption of the crops grown in the five villages contaminated by Heavy metals.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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