Heliyon 9 (2023) e16005

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

# Accumulation of heavy metals and human health risk assessment of vegetable consumption from a farm within the Korle lagoon catchment

Richard Osae [*], Daniel Nukpezah, Daniel Amoako Darko, Samuel Senyo Koranteng, Adelina Mensah

*Institute for Environment and Sanitation Studies, University of Ghana, P.O. Box LG 209, Accra Ghana*

ARTICLE INFO

*Keywords:*
Heavy metals
Korle lagoon catchment
Human health risk assessment
Dietary intake

ABSTRACT

The Korle lagoon is known to have high concentration of heavy metals. The use of land for agriculture and water for irrigation within the Korle Lagoon's catchment constitutes a potential health risk. Due to this, the study assessed the concentration of heavy metals in some vegetables (Amaranth, Spinach, Eggplant, Lettuce, Cauliflower, and Onion) and their corresponding soil from a farm within the Korle Lagoon's catchment. The estimated daily intake (EDI), hazard quotient (HQ), and lifetime cancer risk (LCR) was used to assess their health risks. Among the vegetables tested, heavy metals in lettuce exceeded their recommended guideline level. Additionally, the concentrations of Fe (265.94–3599.60 mg/kg) and Zn (76.77–294.70 mg/kg) in all vegetables were above the recommended guideline level. Also, Zn (227.30–534.57 mg/kg) and Pb (101.53–407.58 mg/kg), in soil were above the recommended guideline level for soil. The results also showed not only the severity of heavy metal pollution of soil in the study area, but also risks that were deemed carcinogenic and noncarcinogenic to both adults and children as a result of consumption of vegetables from the study area. The hazard index for adults (0.46–41.156) and children (3.880–384.122), were high for all vegetables tested and are associated with cancer risk due to high Cr and Pb levels. The risk assessment showed that children may suffer more carcinogenic and noncarcinogenic health risk than adults. The study concluded that vegetables grown within the Korle lagoon's catchment is not suitable for consumption due to the associated adverse health effect.

## 1. Introduction

Heavy metals are natural components of the Earth's crust and can be released by natural processes, but often, anthropogenic activities are responsible for the majority of heavy metal pollution []. This is due to a number of factors, including mining activities, incorrect disposal of industrial effluent, industrial and agricultural practices, and more [1]. Over time, heavy metals contamination has elevated to a global issue as they have the tendency to contaminate water, vegetables, fish, aquatic and terrestrial plants (Ahmad et al., 2010). Many living species depend on heavy metals like Cr, Mn, Co, Cu, Fe, and Zn in trace amounts for their metabolic operations [2]. However, they become extremely toxic in high quantities [3] and the intake of food products with high concentrations of heavy metals

---

[*] Corresponding author.
*E-mail address:* osaerichard@ymail.com (R. Osae).

https://doi.org/10.1016/j.heliyon.2023.e16005
Received 21 September 2022; Received in revised form 10 March 2023; Accepted 28 April 2023

can endanger human health.

In the present era, there is serious concern about food safety. Most food-borne infections are either poisonous or contagious in nature. Typically, they are brought on by bacteria, viruses, parasites, or chemical substances like heavy metals that enter the body through contaminated food or water [4]. Heavy metals may enter the food chain directly through eating of contaminated food or indirectly through plant absorption processes, where they may accumulate in food products that are later ingested [5]. As a result, food crops may include a variety of both essential and non-essential components, such as harmful metals [6,7]. Metals in food crops may also be present due to the characteristics of the growth medium or from irrigation water contaminated with heavy metals [8]. About 90% of the total intake of heavy metals in humans comes from vegetables, with the remaining 10% coming from dermal contact and breathing in polluted dust [9,10]. Essential and non-essential heavy metals are routinely introduced into our food chain as a result of the excessive use of agrochemicals, municipal wastewater, industrial effluent, and raw sewage for irrigation [11].

Heavy metals, some of which are regarded as essential food components, are recognized to be necessary in trace amounts but may cause major health problems in people if taken in excess of the recommended levels. For instance, excessive Cu has been linked to liver damage, while Zn may interact negatively with Cu. High-density lipoprotein (HDL) levels and immunological function have both been linked to zinc [12]. Nickel could induce gastrointestinal discomfort, a rise in red blood cells, and a decrease in lung function at hazardous doses [13]. High Pb concentrations cause health issues like elevated arterial pressure and behavioral issues [14,15]. Additionally, extreme Cd exposure will result in health problems such as skeletal difficulties [15]. According to numerous studies, Cd is extremely hazardous and can lead to cancer [15,16]. Similarly, numerous studies have been conducted on the health consequences of other heavy metals, such as Cr, Pb, As, and Hg [17–19]. Therefore, understanding heavy metals and their potential sources of contamination is a crucial component of risk management and prevention for human health implications. The health risk assessment proposed by the USEPA provides an integrated approach that assesses the health risks posed to people from exposure to particular environmental substances. This can be used as a tool to calculate the potential risks of exposure to heavy metals given the variety of effects that heavy metals have on human health (Jafarzadeh et al., 2020; [20].

The Korle Lagoon serves as a point source of pollution into the Gulf of Guinea. The lagoon, which was once a beautiful setting and supported socioeconomic activity in the urban core, has now turned into a threat to the environment. The rapid growth of industrial activity in the city has been a significant contributor to the pollutant load in the Korle lagoon. Thus, uncontrolled domestic and industrial contaminants as well as raw sewage are discharged into the Korle lagoon. Due to the unrestricted flow of wastewater and other pollutants, the lagoon has become silted. This has resulted in the reduction of the floodwater carrying capacity of the lagoon resulting in serious flooding in the city during rainy seasons [21].

This flooding has the potential to spread the high concentration of metals in the Korle lagoon to the surrounding lands and vegetation [22]. found that the metal concentration in the soils near the Korle lagoon was higher than the WHO criteria. Agriculture is being practiced at the peripherals of the Korle lagoon despite the severe pollution. According to studies, vegetables cultivated on soils

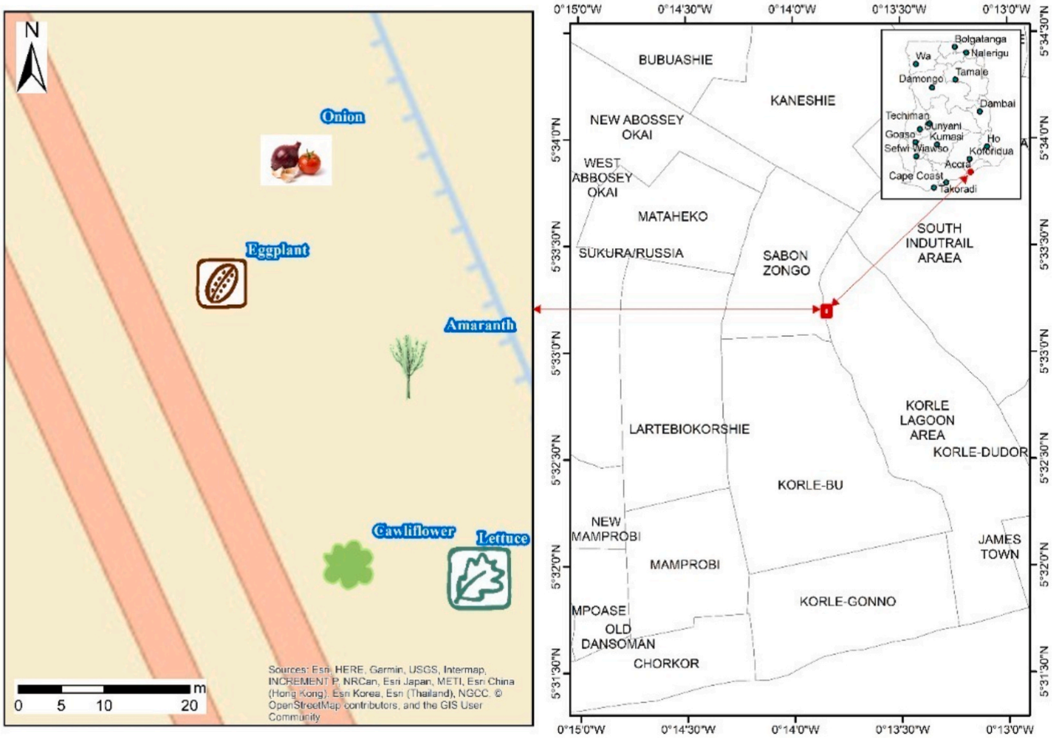

**Fig. 1.** Map of studying area.

with high levels of heavy metal contamination also become polluted [23]. Eventually, heavy metals in the soil and those in the air that are taken up by plant roots or that accumulate on vegetable leaves, respectively, are integrated into the edible sections of the plant tissue and later ingested [24]. Similarly, irrigation water from the Korle Lagoons catchment could serve as a source of heavy metals. Given its degree of contamination, it has not yet been determined if it is safe to carry out agricultural activities in nearby areas because there is the possibility of heavy metal contamination of the farm produce. In this regard, it is advisable to ascertain the level of heavy metals present in the vegetables grown close to the Korle Lagoon and to assess the potential health risks associated with consuming such food. The majority of research on the Korle lagoon has concentrated on the concentration and distribution of heavy metals in the water and sediments of the lagoon. However, there seem to be very little information relating the extent of contamination of the water and sediments to the health risks associated with the consumption of vegetables and other crops grown in the study area. Is it safe to carry out agricultural activities within the catchment of the Korle Lagoon? Therefore, the goal of this study is to assess the concentrations of various heavy metals in vegetables grown on land within the catchment of the Korle Lagoon and to evaluate any potential health risk using the estimated daily intake (EDI), hazard quotient (HQ), hazard index (HI) and lifetime cancer risk (LCR) related to eating vegetables and other crops grown on soils in the study area.

## 2. Materials and methods

### 2.1. Study area

The study focuses on a farmland (Korle farm) located 800 m from the Korle lagoon and covering a land area of 1000 square meters Fig. 1. Within the Korle catchment, the farmland area is susceptible to flooding. Vegetables are the farm's major crops, and a well on the farm is used to provide water for irrigation. Amaranth (*Amaranthus* sp.), Eggplant (*Solanum melongena*), Lettuce (*Lactuca sativa*), Cauliflower (*Brassica oleracea*), Onion (*Allium cepa*), Tomatoes (*Solanum lycopersicum*), Pepper (*Capsicum* sp.), are among the vegetables grown on the farm. The Agbogbloshie market is the primary market where the farm products are marketed in the catchment region. The experimental investigation used a reference farm as control. The reference farm is situated alongside the highway of Tema motorway. This farm was chosen because it is located in the same city as the Korle farm and may have similar geological circumstances, even though it is 16 Km from the Korle lagoon. Additionally, these farms grow identical vegetables and are both situated close to a busy road.

### 2.2. Sampling

In March and September 2021, random samples of vegetables and soil were taken from various locations of the Korle farm and the reference farm. In addition to taking soil and vegetable samples, irrigation water samples were also taken. Amaranth (*Amaranthus* sp.), onion (*Allium cepa*), lettuce (*Lactuca sativa*), Eggplant (*Solanum melongena*) and cauliflower (*Brassica oleracea*), four of each, and the associated soils were taken from each area of the Korle farm, totaling 20 vegetables and 20 soil samples. Similarly, a total of 20 vegetables and their corresponding soils were collected from the reference farm. While vegetables from the Korle farm were labeled with just the names of the vegetables, those from the reference farm had "ref" appended to the vegetable name. The vegetables were placed in coolers containing ice packs and transported to the laboratory for analysis. In the laboratory, the soil was air dried while the vegetables were dried to constant weight in an oven at 65–70 °C and blended with a stainless still blender, sieved through a 2 mm mesh followed by analysis for pH, organic matter, and heavy metals. Results recorded from the analysis of both vegetables and soils were reported as mean ± standard deviation.

### 2.3. pH of soil

Deionized water (40 mL) was added to 10 g of sample in a 50 mL tube. The mixture was then placed on a mechanical shaker and shaken at room temperature for 30 min. A TPS Smartchem electrode probe and meter were used to measure the pH of the samples after 1 h.

### 2.4. Organic matter content of soil

An aliquot of dried soil (0.35g) was weighed into a carbon free combustion boat and treated with 6 M HCL until bubbling stopped. The sample was dried in an oven pre-heated at 40 °C for 24 h and transferred to another oven preheated at 105 °C. The boat was loaded unto the autosampler rack of a LECO analyzer after drying and analyzed for total organic carbon. Organic matter was calculated by multiplying TOC with the conventional factor of 1.724 [25].

$$\text{Organic matter } (\%) = \text{TOC } (\%) \times 1.724 \tag{1}$$

### 2.5. Heavy metal determination

About 2 g each of a <2 mm sieved soil samples were acid digested with 2.5 mL of $HNO_3$ and 2.5 mL of HCL according to USEPA 3050B protocol [26]. The digests were diluted with I mL v/v $HNO_3$ and the heavy metals (Cu, Cd, Cr, Pb, Hg, Ni, Zn, and Fe) were determined using Nexion 2000 ICPMS equipped with micro mist nebulizer and spray chamber using dwell times of 60, 25, 100, 25, 50, 25, 25 ms for As, Cd Hg, Pb, U, Zn, and Cr respectively. All the relative standard deviations of the replicate samples were <20%. Reagent blanks, duplicates, and certified reference material (Enviromat contaminated soil SS-2) were used for quality control and accepted with recovery percentages >90%.

## 3. Data analysis

### 3.1. Geo accumulation index (Igeo)

The geo accumulation index was used to assess the soil contamination by comparing the heavy metal concentration in the soil to a background level according to equation (2).

$$Igeo = log\,2\frac{Cn}{1.5Bn} \tag{2}$$

where Cn is the measured concentration of every heavy metal (mg/kg), and Bn is the geochemical background value of the heavy metals found in the soil [27]. The classification of geo accumulation index [28] and the background levels of heavy metals in continental crust [27] are presented in Tables 1 and 2, respectively.

### 3.2. Transfer factor

The transfer factor is an index for evaluating the transfer potential of heavy metals from soil to plants and was calculated using equation (3) [29].

$$TF = \frac{\mathrm{Mv}}{\mathrm{Ms}} \tag{3}$$

TF = transfer factor
Mv = Concentration of metal in vegetable
Ms = concentration of metal in soil

### 3.3. Health risk assessment

Human health risk assessment involves the estimation of the probability of adverse health effects in humans who are exposed to metals in contaminated environments. It involves exposure assessment, the assessment of noncarcinogenic and carcinogenic risks. Due to the behavioral and physiological differences, the human health risk was conducted for adults and children.

#### 3.3.1. Exposure assessment

Estimated daily intake (EDI) was used to estimate human exposure to heavy metals through direct ingestion according to equation (4) adopted from USEPA methods (1992). Estimations were made for two groups: children (as a sensitive group) and adults (as the general population).

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{4}$$

Where EDI (mg/kg/day) is the estimated daily dose intake through ingestion, C is the concentration of metal (mg/kg) in the food, IR is the ingestion rate (kg/day), EF is the Exposure frequency, ED is the exposure duration, BW (Kg) is the Standard body weight and AT is the time duration of human exposure. The parameters for calculating the estimated daily intake are presented in Table 3.

#### 3.3.2. Non carcinogenic risk

Non carcinogenic health risk involves estimating the likelihood that a given amount of a substance will have adverse health effects over a specified time period. Non carcinogenic health risk was conducted using Hazard quotient and Hazard index.

**Table 1**
Classification criteria for Geo accumulation index (Igeo).

| Igeo level | Class | Contamination status |
|---|---|---|
| Igeo<0 | 0 | Unpolluted |
| 0<Igeo<1 | 1 | Unpolluted to moderately polluted |
| 1<Igeo<2 | 2 | Moderately polluted |
| 2<Igeo<3 | 3 | Moderately to strongly polluted |
| 3<Igeo<4 | 4 | Strongly polluted |
| 4<Igeo<5 | 5 | Strongly polluted |
| 5<Igeo | 6 | Extremely polluted |

**Table 2**
Background levels of heavy metals in the continental crust.

| Element | Background level (mg/kg) |
|---|---|
| Cu | 55 |
| Cd | 0.2 |
| As | 1.8 |
| Cr | 100 |
| Ni | 75 |
| Pb | 12.5 |
| Hg | 0.08 |
| Zn | 70 |
| Fe | 5.63 |

**Table 3**
Parameters for assessment of estimated daily intake.

| Parameter | Value | Reference |
|---|---|---|
| IR | 0.2g/day for children and 0.1g/day for adults | [30] |
| EF | 180 days/year | [30] |
| ED | 6years for children and 24 years for adults | [30] |
| BW | 70 kg for adults and 15 kg for children | [30] |
| AT | 365 *ED | |

*3.3.2.1. Hazard quotient.* The hazard quotient (HQ) was calculated according to equation (5). A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected [31]. The individual reference dose (RD) for the various heavy metals are presented in Table 4 adopted from Ref. [30].

$$HQ = \frac{EDI}{\mathrm{RD}} \tag{5}$$

*3.3.2.2. Hazard index.* Hazard Index (HI) technique was used to evaluate the overall potential for non-carcinogenic health risk posed by many contaminants [31]. The hazard index for a mixture of pollutants is determined using equation (6) [31]:

$$\mathrm{HI} = \sum \mathrm{HQ} \tag{6}$$

If the HI value is less than one, the exposed population is unlikely to experience obvious adverse health effects. If the HI value exceeds one, then adverse health effects may occur [31].

### 3.3.3. *Carcinogenic risk assessment*

Carcinogenic risks are estimated by calculating the probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The carcinogenic health risk is calculated using a cancer slope factor as shown in equation (7). 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.

$$\mathrm{LCR} = \mathrm{EDI} \times C\,\mathrm{SF} \tag{7}$$

Where, LCR is the lifetime cancer risk and CSF is the cancer slope factor (mg/kg/day).

LCR above $1 \times 10^{-4}$ is viewed as unacceptable, risks below $1 \times 10^{-6}$ are not considered to have significant health effects, and risk lying between $1 \times 10^{-4}$ and $1 \times 10^{-6}$ is considered an acceptable range [31]. The individual cancer slope factors as adopted from the [31] are presented in Table 4.

**Table 4**
Reference dose and cancer slope factor (CSF) for heavy metals.

| | Ref Dose (mg/kg/day) | CSF (mg/kg/day) |
|---|---|---|
| Cd | 0.001 | 0.0061 |
| Cr | 1.5 | 0.041 |
| Pb | 0.04 | 0.0085 |
| Fe | 0.7 | |
| Zn | 0.3 | |
| Cu | 0.04 | |
| Ni | 0.02 | 0.00084 |
| As | 0.0003 | |
| Hg | 0.0001 | |

## 4. Statistical analysis

Exploratory data analysis was used to determine the mean and standard deviations. Results were expressed as mean ± Standard deviation. Results of heavy metals, pH, and organic matter from reference farm and the Korle farm were compared using analysis of variance at significance level of 0.05. PCA was used to reduce the dimensionality of data to make the data more interpretative and Correlation analysis was performed to determine the relationship between the variables. PCA, correlation and exploratory data analysis were done using SPSS 24. Prior to statistical analysis, normality of data was checked using Shapiro-Wilks test and the data was found to have a normal distribution.

## 5. Results

### 5.1. pH and organic matter in soil

Results for pH and organic matter for the soil from the Korle farm and the soil from the reference farm are presented in Table 5. The pH was in the range of 7.06–8.47 for the soil from the Korle farm and 7.03–7.12 for the soil from the reference farm. The highest pH was recorded for the Eggplant soil which was highly alkaline (8.47). The pH of the soil from the Korle farm shows a statistically significance difference ($P = 0.016$; $P < 0.05$) from the pH of soil from the reference farm. The organic matter content in the soil from the Korle farm was high and in the range of 3.28–6.15%. That of the reference farm was relatively low and in the range of 1.74–2.01%. Similar to the pH, there was a statistically significant difference ($P = 0.0003$; $P < 0.05$) between the organic matter content of soil from the Korle farm and that of the reference farm.

### 5.2. Concentration of metals in vegetables

The concentrations of metals found in vegetables are shown in Table 6. For Cu, Cd, As, Cr, Ni, Pb, Hg, Zn, and Fe, the results for vegetables from the Korle farm varied from 3.82 to 41.44 mg/kg, 0.12–1.23 mg/kg, 0.19–1.77 mg/kg, 1.49–17.42 mg/kg, 0.38–6.50 mg/kg, 1.51–174.84 mg/kg, 0.01–0.09 mg/kg, 34.94–294.70 mg/kg, respectively. When compared to amaranth (0.01–673.60 mg/kg), eggplant (0.01–711.12 mg/kg), cauliflower (0.09–597.19 mg/kg), and onion (0.02–3599.60 mg/kg), lettuce (0.02–3599.60 mg/kg) had the highest concentration of all the metals. With the exception of Fe and Zn, the majority of the vegetables had metal concentrations that were below the indicated guideline level. Additionally, every metal found in lettuce—all but Ni—exceeded the acceptable limit. Vegetables from the Korle farm generally have higher concentrations of metals than those from the reference farm (see ).

### 5.3. Concentration of metals in soil (mg/kg)

For Cu, Cd, As, Cr, Ni, Pb, Hg, Zn, and Fe, the results for metals in soils from the Korle farm varied from 29.23 to 77.97 mg/kg, 0.14–1.03 mg/kg, 1.96–3.56 mg/kg, 15.31–27.19 mg/kg, 6.71–15.36 mg/kg, 75.06–407.58 mg/kg, 0.016–0.029 mg/kg, 227.30–534.57, respectively Table 7. Except for Fe (17848 mg/kg), which had the highest concentration in the soil where cauliflower was grown, the soil where lettuce was grown had the highest metal concentration (0.03–13835.75 mg/kg). Amaranth, eggplant, cauliflower, and onion had soil metal concentrations that ranged from 0.02 to 7080.32 mg/kg, 0.03 to 7908.32 mg/kg, 0.29 to 17848, and 0.24 to 16745, respectively. Except for Zn and Pb, all values were below the acceptable guideline level for soil. Generally, the concentration of metals in the soil from the Korle farm were higher than those from the reference farm.

### 5.4. Concentration of metals in irrigation water from the Korle farm (mg/L)

The concentrations of heavy metals in the irrigation water were low. Cu, Cd, Ni, Hg, As, and Zn were not detected, however, trace amounts of Cr (0.002–0.004 mg/L) and Fe (0.05–0.17 mg/L) were recorded Table 8. The results were below the irrigation water guideline level from WHO/FAO.

**Table 5**
Mean organic matter and pH in soil.

| Section of farm | pH | Organic matter (%) |
|---|---|---|
| Amaranth | 7.94 ± 0.02 | 5.19 ± 0.02 |
| Lettuce | 7.52 ± 0.01 | 4.38 ± 0.03 |
| Eggplant | 8.47 ± 0.08 | 4.92 ± 0.01 |
| Cauliflower | 7.19 ± 0.06 | 6.15 ± 0.02 |
| Onion | 7.06 ± 0.02 | 3.28 ± 0.02 |
| Amaramth Ref | 7.12 ± 0.04 | 2.01 ± 0.02 |
| Eggplant Ref | 7.06 ± 0.04 | 1.74 ± 0.01 |
| lettuce Ref | 7.05 ± 0.03 | 1.86 ± 0.01 |
| Cauliflower Ref | 7.02 ± 0.01 | 1.92 ± 0.02 |
| Onion Ref | 7.08 ± 0.02 | 1.78 ± 0.02 |

**Table 6**
Concentration of metals in vegetables (mg/kg).

| Sample Id | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Amaranth | 12.42 ± 0.87 | 0.12 ± 0.01 | 0.49 ± 0.03 | 5.96 ± 0.42 | 1.75 ± 0.08 | 8.23 ± 0.39 | 0.01 ± 0.001 | 76.77 ± 4.08 | 673.60 ± 8.50 |
| Lettuce | 41.44 ± 2.07 | 1.23 ± 0.05 | 1.77 ± 0.11 | 17.42 ± 0.98 | 6.50 ± 0.33 | 174.84 ± 8.59 | 0.02 ± 0.003 | 294.70 ± 11.34 | 3599.60 ± 103.11 |
| Eggplant | 17.33 ± 0.47 | 0.55 ± 0.01 | 0.71 ± 0.02 | 6.99 ± 0.13 | 2.04 ± 0.06 | 12.05 ± 0.94 | 0.01 ± 0.002 | 111.99 ± 2.47 | 711.12 ± 11.06 |
| Colliflower | 10.70 ± 0.70 | 0.36 ± 0.02 | 0.32 ± 0.09 | 2.74 ± 0.20 | 1.37 ± 0.09 | 5.54 ± 0.32 | 0.09 ± 0.006 | 203.25 ± 11.09 | 597.19 ± 116.69 |
| Onion | 3.82 ± 0.19 | 0.60 ± 0.02 | 0.19 ± 0.04 | 1.49 ± 0.08 | 0.38 ± 0.02 | 1.51 ± 0.06 | 0.051 ± 0.003 | 34.94 ± 1.33 | 265.94 ± 27.72 |
| Amaranth Ref. | 11.57 ± 0.52 | 0.08 ± 0.001 | ND | 4.82 ± 0.59 | 2.89 ± 0.33 | 1.23 ± 0.07 | 0.01 ± 0.001 | 52.72 ± 2.04 | 125.51 ± 12.24 |
| Lettuce Ref. | 28.64 ± 1.11 | 0.2 ± 0.09 | ND | 8.02 ± 0.38 | 7.68 ± 0.34 | 3.75 ± 0.32 | 0.01 ± 0.001 | 24.17 ± 1.04 | 328.84 ± 28.23 |
| Eggplant Ref. | 10.77 ± 0.64 | 0.2 ± 0.02 | ND | 3.84 ± 0.17 | 3.19 ± 0.12 | 1.36 ± 0.09 | ND | 27.02 ± 1.08 | 133.56 ± 17.32 |
| Cauliflower Ref. | 22.62 ± 0.64 | 0.08 ± 0.001 | 0.33 ± 0.15 | 14.87 ± 0.30 | 9.33 ± 0.24 | 2.7 ± 0.02 | 0.04 ± 0.001 | 129.54 ± 1.58 | 271.92 ± 19.38 |
| Onion ref | 3.38 ± 3.38 | 0.03 ± 0.03 | ND | 1.07 ± 1.07 | 0.48 ± 0.48 | 0.05 ± 0.05 | ND | 24.23 ± 3.05 | 5.7 |
| **WHO/FAO** | **40** | **0.02** | **0.15** | **1.3** | **10** | **5** | **0.02** | **60** | **48 ± 18.52** |

ND-Not detected.

**Table 7**
Concentration of metals in soil (mg/kg).

| Farm section | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Amaranth soil | 29.23 ± 1.44 | 0.14 ± 0.29 | 1.96 ± 0.09 | 15.31 ± 0.83 | 6.71 ± 0.59 | 75.06 ± 8.68 | 0.016 ± 0.002 | 227.30 ± 65.75 | 7080.16 ± 78.40 |
| Lettuce soil | 77.97 ± 10.7 | 1.03 ± 0.24 | 3.51 ± 0.36 | 36.88 ± 3.69 | 15.36 ± 2.53 | 407.58 ± 64.68 | 0.029 ± 0.004 | 534.57 ± 78.13 | 13835.75 ± 112.46 |
| Eggplant Soil | 41.69 ± 0.19 | 0.40 ± 0.06 | 2.48 ± 0.42 | 19.91 ± 4.88 | 8.71 ± 1.83 | 134.89 ± 17.23 | 0.03 ± 0.02 | 343.67 ± 123.48 | 7908.32 ± 3896.73 |
| cauliflower soil | 51.14 ± 7.53 | 0.46 ± 0.1 | 2.24 ± 0.30 | 27.19 ± 2.44 | 8.99 ± 1.57 | 240.56 ± 54.91 | 0.29 ± 0.050 | 477.51 ± 233.76 | 17848 ± 3896.73 |
| Onion soil | 43.33 ± 4.59 | 0.52 ± 0.1 | 2.28 ± 0.16 | 23.29 ± 2.18 | 9.72 ± 1.59 | 101.52 ± 13.18 | 0.24 ± 0.018 | 357.16 ± 43.65 | 16475 ± 1145.47 |
| Amaranth soil ref | 40.96 ± 2.02 | 0.18 ± 0.31 | 17.3 ± 4.25 | 39.38 ± 6.24 | 22.38 ± 3.62 | 8.82 ± 3.25 | 0.01 ± 0.01 | 31.02 ± 8.02 | 20167.48 ± 896.87 |
| Lettuce Soil ref | 19.75 ± 0.96 | 0.079 ± 0.12 | 1.06 ± 0.24 | 42.27 ± 4.28 | 28.74 ± 1.94 | 8.87 ± 2.24 | 0.015 ± 0.01 | 27.27 ± 6.33 | 18316.64 ± 2287.35 |
| Eggplant Soil ref | 22.66 ± 1.26 | 0.31 ± 0.18 | 0.95 ± 0.12 | 42.93 ± 6.14 | 33.71 ± 4.59 | 12.31 ± 5.19 | 0.02 ± 0.02 | 33.1 ± 7.14 | 20167.48 ± 974.62 |
| Cauliflower Soil ref | 59.75 ± 6.32 | 0.8 ± 0.24 | 1.06 ± 0.05 | 42.27 ± 9.21 | 28.74 ± 3.10 | 8.87 ± 2.04 | 0.02 ± 0.03 | 27.28 ± 5.01 | 15450.85 ± 1534.07 |
| Onion Soil ref | 19.27 ± 4.25 | 0.07 ± 0.11 | 0.71 ± 0.04 | 18.83 ± 3.41 | 23.01 ± 1.67 | 9.14 ± 1.52 | 0.04 ± 0.02 | 23.7 ± 4.42 | 24107.96 ± 1032.12 |
| [32] | **100** | **1** | **5** | **100** | **50** | **60** | **0.3** | **200** | |

### 5.5. Geoaccumulation index

According to the geoaccumulation index results, soil from the Korle farm is unpolluted with Cu, Cd, As, Cr, Ni, or Hg Table 9. However, it is moderately to strongly polluted with Pb (2.9), moderately polluted with Zn (1.6), and extremely polluted with Fe (10.2).

**Table 8**
Concentration of metals in irrigation water (mg/L).

| | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| IR Water | ND | ND | ND | 0.004 | ND | ND | ND | ND | 0.17 |
| IR Water | ND | ND | ND | 0.002 | ND | ND | ND | ND | 0.168 |
| IR Water | ND | ND | ND | 0.003 | ND | ND | ND | ND | 0.17 |
| IR water Ref | ND | ND | ND | ND | ND | ND | ND | ND | 0.05 |
| WHO/FAO | 0.2 | 0.01 | 0.1 | 0.1 | 0.2 | 5 | 1 | 2 | – |

ND-Not detected.

With the exception of Fe (11.15), which was found to be extremely polluted, the reference farm is unpolluted with any of the other heavy metals analyzed.

### 5.6. *Transfer factor from soil to vegetables*

The average transfer factor was in the order of Cd (0.61) > Hg (0.41) >As (0.33)>Cu (0.3) >Cr (0.27) > Ni (0.20) > Pb (0.13) > Fe (0.11). The highest transfer factor for lettuce and eggplant was that of Cd (1.24, 1.36, respectively). Amaranth, cauliflower, and onions all had Cd transfer factors that were observed at 0.003, 0.21, and 0.28, respectively. In comparison to As (0.23–0.51), Zn (0.35–0.56), Cu (0.29–0.54), Pb (0.08–0.44), Cr (0.26–0.48), and Ni (0.19–0.43), Fe (0.09–0.26) generally observed low transfer factors. In general, lettuce (0.26–1.24) and eggplant (0.09–1.36) exhibited the highest transfer factors. There was a statistically significant difference in transfer factors for the different vegetables ($P = 0.004$; $P < 0.05$). Similarly, a statistically significant difference ($P = 0.004$; $P < 0.05$) was seen when the transfer factors of the various heavy metals were evaluated. In general, the reference farm had higher Zn, Hg, Pb, and Cu transfer factors than it did for As, Cr, Ni, and Fe. With the exception of Ni, Pb, and Hg, the eggplant variety had the highest transfer factor from the reference farm (see Table 10).

### 5.7. *Health risk assessment*

Table 11shows the EDI, HQ, HI, and LCR values for each vegetable (a-adults, b-children). The EDI for adults were below the recommended daily intake for all metals, with the exception of As (0.001) in eggplant, and Pb (0.123), As (0.001), and Fe (2.536) in lettuce. The estimated daily intake for Amaranth (Cu-0.081,Pb-0.054), lettuce (Cu-0.273,Pb-1.150), and eggplant (Cu-0.114,Pb-0.079) for Cu and Pb from the Korle farm were higher than the Estimated Daily Intake (EDI) for children. The EDI for arsenic in amaranth (0.003), lettuce (0.012), eggplant (0.005), and cauliflower (0.006) were all above the acceptable daily limit for children. Similarly, Pb in amaranth (0.054), lettuce (1.149), and eggplant (0.079), Ni (0.043) in lettuce, and Fe (23.669) in lettuce were all above the daily allowance for children. Additionally, HQ for lettuce (0.008–30.794) for adults was high. For Cu, Cd, As, Pb, Zn, and Fe, HQ for lettuce (6.459–287.413) was higher than the permissible HQ of that for children. Similarly, HQ for Fe exceeded the limit for all vegetables for children, while for adults, HQ for Fe (3.623) in lettuce exceeded the limit. The Hazard index for lettuce (0.46–41.156) for adults and children's hazard index for all vegetables tested from the Korle farm (3.88–284.122) both exceeded the recommended limits. When compared to adults, children were at a higher risk for non-carcinogenic health risks. In general, the vegetables from the reference farm had low Hazard indices, with the exception of Amaranth (1.98) and Lettuce (2.52) for adults. However, the recommended HI for children was exceeded for all vegetables tested (see Table 12).

### 5.8. *Carcinogenic health risk*

Figs. 2 and 3 show the LCR of heavy metals from vegetable consumption (see ). The acceptable levels of Cr and Pb in lettuce from the Korle farm were exceeded for adults. The acceptable limit for all metals was not exceeded in any other vegetables. For children, the recommended limits for Pb and Cr for amaranth, spinach, lettuce, and eggplant from the Korle farm were all exceeded. Cauliflower and onions posed no cancer risk. The LCR for vegetables from the reference farm were below the recommended levels for adults. The Cr levels in lettuce, eggplant, cauliflower, amaranth, and onion from the reference farm exceeded the recommended limit for children and are potentially carcinogenic.

### 5.9. *Correlation*

Pearson correlation was used to determine the correlation between heavy metals, pH, and organic matter at a significance level of 0.01 Table 13. With the exception of Fe, all the heavy metals showed extremely high correlation. Similarly, there was a moderate correlation between heavy metals and organic matter. However, there was a low negative correlation between heavy metals and pH

**Table 9**

Geoaccumulation index of heavy metals in soil.

| Farm section | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Amaranth | −1.50 | −5.70 | −0.47 | −3.29 | −4.07 | 2.00 | −2.95 | 1.11 | 9.71 |
| Lettuce | −0.08 | −2.86 | 0.38 | −2.02 | −2.87 | 4.44 | −2.05 | 2.35 | 10.68 |
| Eggplant | −0.98 | −4.23 | −0.12 | −2.91 | −3.69 | 2.85 | −1.95 | 1.71 | 9.87 |
| Cauliflower | −0.69 | −4.02 | −0.27 | −2.46 | −3.64 | 3.68 | 1.28 | 2.19 | 9.87 |
| Onion | −1.84 | −3.91 | −1.25 | −3.83 | −4.87 | 1.59 | −3.09 | 0.58 | 11.05 |
| **Average** | **−1.018** | **−4.144** | **−0.346** | **−2.902** | **−3.828** | **2.912** | **−1.752** | **1.588** | **10.236** |
| Amaranth ref | −1.86 | −6.08 | −1.51 | −1.80 | −1.74 | −0.61 | −2.96 | −1.67 | 11.22 |
| Lettuce ref | −2.06 | −6.56 | −1.35 | −1.83 | −1.97 | −1.08 | −2.98 | −1.94 | 11.08 |
| Eggplant ref | −2.10 | −6.77 | −1.92 | −2.99 | −2.29 | −1.04 | −1.63 | −2.15 | 11.22 |
| Cauli flower ref | −1.98 | −6.58 | 2.68 | −1.93 | −2.33 | −1.09 | −3.08 | −1.76 | 10.84 |
| Onion ref | −1.69 | −5.05 | −1.56 | −1.84 | −2.69 | −0.53 | −2.82 | −0.86 | 11.48 |
| **Average Ref** | **−1.96** | **−6.27** | **−0.83** | **−2.04** | **−2.16** | **−0.90** | **−2.74** | **−1.72** | **11.15** |

**Table 10**
Transfer factor from soil to vegetables.

| | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Amaranth | 0.43 | 0.003 | 0.25 | 0.39 | 0.26 | 0.11 | 0.63 | 0.36 | 0.1 |
| Lettuce | 0.54 | 1.24 | 0.51 | 0.48 | 0.43 | 0.44 | 0.75 | 0.56 | 0.26 |
| Eggplant | 0.42 | 1.36 | 0.29 | 0.36 | 0.24 | 0.09 | 0.4 | 0.35 | 0.09 |
| Cauliflower | 0.09 | 0.21 | 0.3 | 0.08 | 0.06 | 0.01 | 0.11 | 0.05 | 0.09 |
| Onion | 0.04 | 0.28 | 0.28 | 0.04 | 0.01 | −0.01 | 0.17 | 0.03 | 0.01 |
| **Average** | **0.30** | **0.61** | **0.33** | **0.27** | **0.20** | **0.13** | **0.41** | **0.27** | **0.11** |
| Amaranth ref | 0.48 | 0.64 | −0.12 | 0.09 | 0.09 | 0.11 | 0.31 | 0.82 | 0.01 |
| Lettuce ref | 0.48 | 0.25 | −0.24 | 0.19 | 0.27 | 0.42 | 0.45 | 0.89 | 0.02 |
| Eggplant ref | 0.6 | 1.18 | −0.03 | 0.26 | 0.13 | 0.13 | 0.2 | 2.22 | 0.01 |
| Cauli flower ref | 0.55 | 0.44 | 0.02 | 0.38 | 0.42 | 0.31 | 2.82 | 1.68 | 0.02 |
| Onion ref | 0.13 | 0.12 | −0.11 | 0.03 | 0.03 | −0.02 | 0.17 | 0.42 | 0.01 |
| **Average ref** | **0.45** | **0.53** | **−0.10** | **0.19** | **0.19** | **0.19** | **0.79** | **1.21** | **0.01** |

**Table 11**
Estimated daily intake (mg/kg/day) for adults (a) and children (b).

| EDI | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe |
|---|---|---|---|---|---|---|---|---|---|
| **A: Adults** | | | | | | | | | |
| Amaranth | 0.009 | 0.000 | 0.000 | 0.004 | 0.001 | 0.006 | 0.000 | 0.054 | 0.475 |
| Lettuce | 0.029 | 0.001 | 0.001 | 0.012 | 0.005 | 0.123 | 0.000 | 0.208 | 2.536 |
| Eggplant | 0.012 | 0.000 | 0.001 | 0.005 | 0.001 | 0.009 | 0.000 | 0.079 | 0.501 |
| Cauliflower | 0.001 | 0.000 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.421 |
| Onion | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.187 |
| Amaranth Ref | 0.004 | 0.000 | 0.0002 | 0.001 | 0.000 | 0.007 | 0.000 | 0.028 | 4.847 |
| Lettuce Ref | 0.020 | 0.000 | −0.0002 | 0.006 | 0.005 | 0.003 | 0.000 | 0.017 | 0.232 |
| Cauliflower Ref | 0.016 | 0.000 | 0.0002 | 0.011 | 0.007 | 0.002 | 0.000 | 0.037 | 0.192 |
| Eggplant Ref | 0.008 | 0.000 | −0.0003 | 0.003 | 0.002 | 0.001 | 0.000 | 0.019 | 0.094 |
| Onion Ref | 0.008 | 0.000 | −0.0001 | 0.003 | 0.002 | 0.001 | 0.000 | 0.037 | 0.088 |
| ADI | 0.04 | 0.001 | 0.0003 | 1.5 | 0.02 | 0.04 | 0.0001 | 0.3 | 0.7 |
| **B: Children** | | | | | | | | | |
| Amaranth | 0.081 | 0.001 | 0.003 | 0.039 | 0.012 | 0.054 | 0.0001 | 0.505 | 4.429 |
| Spinach | 0.098 | 0.003 | 0.005 | 0.046 | 0.014 | 0.078 | 0.0001 | 0.480 | 4.829 |
| Lettuce | 0.273 | 0.008 | 0.012 | 0.115 | 0.043 | 1.150 | 0.0001 | 1.938 | 23.669 |
| Eggplant | 0.114 | 0.004 | 0.005 | 0.046 | 0.0134 | 0.079 | 0.0001 | 0.736 | 4.676 |
| Cauliflower | 0.005 | 0.000 | 0.001 | 0.001 | 0.001 | 0.002 | 0.0000 | 0.073 | 3.927 |
| Onion | 0.001 | 0.000 | 0.000 | 0.001 | 0.0001 | 0.000 | 0.0000 | 0.009 | 1.749 |
| Amaranth Ref | 0.0328 | 0.001 | 0.0012 | 0.007 | 0.004 | 0.067 | 0.0002 | 0.261 | 45.240 |
| Lettuce Ref | 0.1883 | 0.001 | −0.002 | 0.053 | 0.051 | 0.025 | 0.0000 | 0.159 | 2.162 |
| Eggplant Ref | 0.1487 | 0.001 | 0.002 | 0.098 | 0.061 | 0.018 | 0.0003 | 0.342 | 1.788 |
| Cauliflower Ref | 0.0708 | 0.001 | −0.003 | 0.025 | 0.021 | 0.009 | 0.0000 | 0.178 | 0.878 |
| Onion Ref | 0.0761 | 0.0005 | −0.001 | 0.032 | 0.019 | 0.008 | 0.0001 | 0.347 | 0.825 |
| ADI | 0.04 | 0.001 | 0.0003 | 1.5 | 0.02 | 0.04 | 0.0001 | 0.3 | 0.7 |

and all the other heavy metals and Fe.

### *5.10. Principal component analysis (PCA)*

The dimension of original data sets from the Korle farm were reduced through the use of principal component analysis (PCA), which also made it simple to identify the sources of heavy metals. Based on the Eigen values criteria, where Eigen values greater than one were considered to be significant, the number of significant principal components (PCs) was calculated. Two principal components were identified which explained 96% of the total variance. Cd, Pb, Cu, Cr, Ni, Zn, As, and Hg were heavily loaded in principal component 1, which explained 76% of the total variance Table 14. Principal component 2 had strong correlations to Fe, pH, and organic matter and explained 17% of the total variance Table 14. The plot of the principal component in space is shown in Fig. 4. Values that are close together indicate a strong correlation.

## 6. Discussion

The concentration of metals in the soil and vegetables from the Korle farm were much higher than those from the reference farm. However, it was observed that the reference farm had high levels of Fe contamination but no other heavy metal pollution (Cu, Cd, As, Pb, Zn, Ni, or Hg). When the two farms were compared, the results for Cd, Cr, and Fe showed no statistically significant difference ($P > 0.05$). This implies that there may be similar sources of pollution for these metals at both farms [33]. This is because, . [34]; recorded

**Table 12**
Hazard Quotient and Hazard index for adults (a) and children (b).

| | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe | **HI** |
|---|---|---|---|---|---|---|---|---|---|---|
| **A: Adults** | | | | | | | | | | |
| Amaranth | 0.219 | 0.083 | 1.143 | 0.003 | 0.062 | 1.449 | 0.022 | 0.180 | 0.678 | 3.838 |
| Spinach | 0.261 | 0.325 | 1.764 | 0.003 | 0.077 | 2.091 | 0.031 | 0.171 | 0.739 | 5.463 |
| Lettuce | 0.730 | 0.864 | 4.166 | 0.008 | 0.229 | 30.794 | 0.050 | 0.692 | 3.623 | 41.156 |
| Eggplant | 0.305 | 0.378 | 1.676 | 0.003 | 0.072 | 2.122 | 0.027 | 0.263 | 0.716 | 5.562 |
| Cauliflower | 0.012 | 0.015 | 0.213 | 0.000 | 0.003 | 0.057 | 0.013 | 0.026 | 0.601 | 0.941 |
| Onion | 0.003 | 0.020 | 0.104 | 0.000 | 0.001 | 0.010 | 0.007 | 0.003 | 0.268 | 0.416 |
| Amaranth Ref | 0.504 | 0.138 | 0.000 | 0.004 | 0.270 | 0.660 | 0.016 | 0.057 | 0.331 | 1.980 |
| Lettuce Ref | 0.398 | 0.057 | 0.765 | 0.007 | 0.329 | 0.475 | 0.094 | 0.122 | 0.274 | 2.520 |
| Eggplant Ref | 0.190 | 0.141 | 0.000 | 0.002 | 0.112 | 0.239 | 0.011 | 0.063 | 0.134 | 0.893 |
| Cauliflower Ref | 0.204 | 0.057 | 0.000 | 0.002 | 0.102 | 0.217 | 0.018 | 0.124 | 0.126 | 0.850 |
| Onion Ref | 0.060 | 0.019 | 0.000 | 0.001 | 0.017 | 0.008 | 0.007 | 0.057 | 0.006 | 0.173 |
| Lettuce Ref | 0.219 | 0.083 | 1.143 | 0.003 | 0.062 | 1.449 | 0.022 | 0.180 | 0.678 | 3.838 |
| **B: Children** | | | | | | | | | | |
| Amaranth | 2.042 | 0.770 | 10.666 | 0.026 | 0.576 | 13.527 | 0.209 | 1.683 | 6.327 | 35.826 |
| Spinach | 2.440 | 3.038 | 16.461 | 0.031 | 0.718 | 19.514 | 0.285 | 1.600 | 6.898 | 50.985 |
| Lettuce | 6.812 | 8.066 | 38.886 | 0.076 | 2.135 | 287.413 | 0.463 | 6.459 | 33.812 | 384.122 |
| Eggplant | 2.849 | 3.528 | 15.639 | 0.031 | 0.670 | 19.806 | 0.251 | 2.455 | 6.680 | 51.908 |
| Cauliflower | 0.115 | 0.140 | 1.992 | 0.001 | 0.031 | 0.528 | 0.123 | 0.243 | 5.610 | 8.784 |
| Onion | 0.031 | 0.183 | 0.969 | 0.000 | 0.007 | 0.097 | 0.066 | 0.029 | 2.498 | 3.880 |
| Amaranth Ref | 4.708 | 1.288 | 0.000 | 0.035 | 2.524 | 6.159 | 0.149 | 0.530 | 3.089 | 18.482 |
| Lettuce Ref | 3.718 | 0.528 | 7.136 | 0.065 | 3.069 | 4.435 | 0.877 | 1.140 | 2.554 | 23.522 |
| Eggplant Ref | 1.770 | 1.318 | 0.000 | 0.017 | 1.048 | 2.232 | 0.105 | 0.592 | 1.255 | 8.337 |
| Cauliflower Ref | 1.902 | 0.531 | 0.000 | 0.021 | 0.949 | 2.024 | 0.170 | 1.156 | 1.179 | 7.932 |
| Onion Ref | 0.556 | 0.175 | 0.000 | 0.005 | 0.157 | 0.078 | 0.061 | 0.531 | 0.054 | 1.617 |

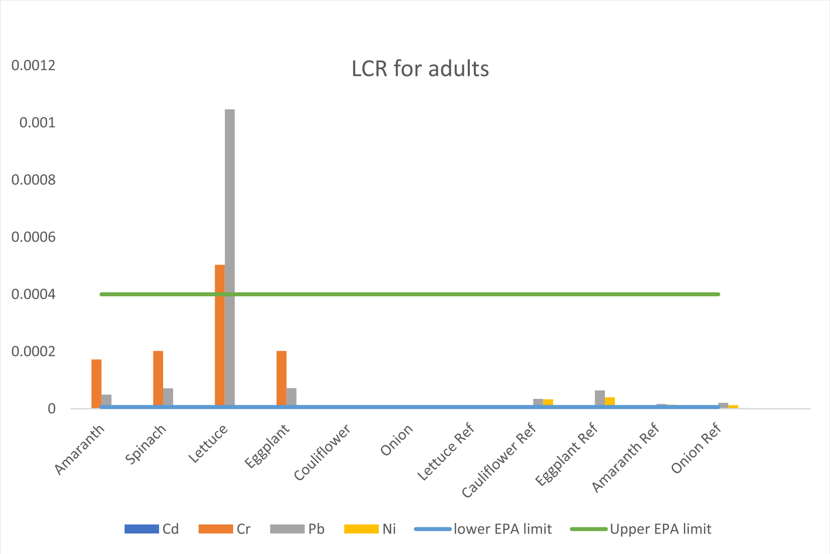

**Fig. 2.** LCR for adults.

high Cr levels in plants grown along roads with heavy traffic. Also, high Fe vehicular emission have been reported by Refs. [35–37]. Furthermore, Cd is mostly used in the electro-less Nickel–Cadmium bath phase during the brake manufacturing process of vehicles, which provides the brake coating that produces corrosion-resistant brake parts [38]. During operation, the friction created during braking corrodes the Cd layer and releases Cd particles into the environment [38]. Antisary et al. (2015) [39]; and Suleiman (2018) demonstrated that vegetation growing next to a busy road can accumulate high concentration of heavy metals. Given that both the Korle farm and the reference farm are close to a road with significant traffic, the sources of Cd, Cr and Fe can be attributed to vehicular emissions. There was however, a statistically significant difference ($P < 0.05$) in the levels of Cu, Zn, Pb, Ni, and As between the reference farm and the Korle farm. However, the soil from the Korle farm had higher concentrations of As, Pb, Hg, and Zn than the reference farm. According to this, activities within the Korle catchment also contribute to an increase in the amount of pollutants there, despite the high pollution levels from outside sources like vehicle emissions.

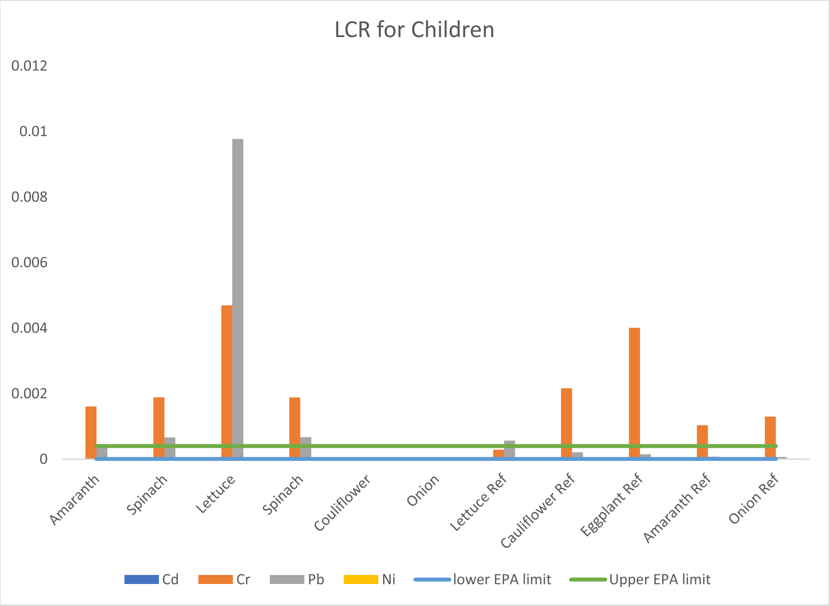

**Fig. 3.** LCR for children.

**Table 13**
Correlation between heavy metals (As, Cd, Cu, Cr, Ni, Fe, Hg, Pb, Zn), pH and organic matter.

| | Cu | Cd | As | Cr | Ni | Pb | Hg | Zn | Fe | pH | OM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cu | 1 | | | | | | | | | | |
| Cd | .999** | 1 | | | | | | | | | |
| As | 1.000** | .999** | 1 | | | | | | | | |
| Cr | 1.000** | .999** | 1.000** | 1 | | | | | | | |
| Ni | 1.000** | .999** | 1.000** | 1.000** | 1 | | | | | | |
| Pb | 1.000** | 1.000** | .999** | .999** | .999** | 1 | | | | | |
| Hg | 1.000** | .999** | 1.000** | 1.000** | 1.000** | .999** | 1 | | | | |
| Zn | 1.000** | 1.000** | 1.000** | .999** | .999** | 1.000** | 1.000** | 1 | | | |
| Fe | −.375 | −.354 | −.380 | −.376 | −.377 | −.369 | −.382 | −.379 | 1 | | |
| pH | −.464 | −.479 | −.455 | −.464 | −.462 | −.466 | −.452 | −.455 | −.560 | 1 | |
| OM | .602 | .598 | .601 | .601 | .602 | .609 | .605 | .614 | −.789 | .112 | 1 |

**. Correlation is significant at the 0.01 level (2-tailed).

**Table 14**
Loading plot of the principal components.

| | Component | |
|---|---|---|
| | 1 | 2 |
| Cd | .994 | |
| Pb | .992 | |
| Cu | .992 | |
| Cr | .992 | |
| Ni | .992 | |
| Zn | .991 | |
| As | .990 | |
| Hg | .990 | |
| Fe | | −.949 |
| pH | −.572 | .757 |
| OM | .545 | .713 |

High metal concentrations were found in the soil as well as the vegetables from the Korle farm. This agrees with the findings of Fosu Mensah et al. (2017), which showed high concentrations of heavy metals in lands around the Korle Lagoon. Except for the lettuce soil, which exceeded the recommended guideline level for all metals, all other soils had metal concentrations that were generally within their recommended guideline limits. According to the geo accumulation index values, the soil from the Korle farm is extremely

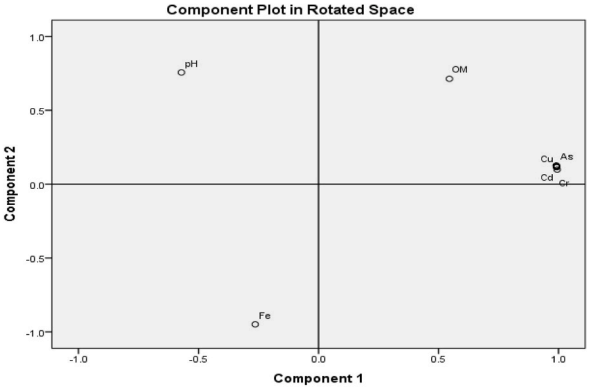

**Fig. 4.** Loading plot of the principal component.

polluted with Fe, moderately polluted with Zn, and moderately to strongly polluted with Pb. This corroborates the findings of Osae et al. (2020) who showed that Fe, Zn and Pb has high mobility in sediments of the Korle Lagoon. According to them, these metals have the potential to contaminate residential areas and farmlands within the Korle Lagoons' catchment. There was a moderate correlation between the organic matter and the heavy metals, which suggest anthropogenic activities as a possible source of contamination. It was however observed that the metals had a strong correlation with one another, suggesting they share a common origin [40]. This was further corroborated by the PCA, which showed that there was no statistically significant difference between the loadings and that the PC1, which accounts for 76% of the total variance, had a high loading (0.992 ± 0.001) (Fig. 4) of all the heavy metals tested. This suggests that a common origin that has already been contaminated with various heavy metals is the main source of heavy metal pollution.

Thus, the Korle Lagoon, which has been documented to have high concentration of heavy metals, can be considered the source of the metals in this farmland [22,41–43]. The primary sources of pollutants in the Korle Lagoon include treated and untreated municipal sewage, treated and untreated industrial sewage, household waste, and waste from agricultural fields [44]. Heavy metals are among the many toxic pollutants that end up in the Korle Lagoon and are crucial because of their toxicity and persistence in the environment. The Agbogbloshie E-waste site which is situated at the peripherals of the Lagoon is chiefly responsible for the majority of the heavy metals found in the Korle lagoon [45–47]. Due to the enormous volume of used electronic and electrical equipment's (EEE) imports, used EEE is widely available in Ghana and may be purchased at relatively low costs. This makes these items more accessible than in many countries and gives many Ghanaians the chance to utilize EEE in their daily life [48]. However, used goods have a shorter lifespan than new ones, which increases the amount of e-waste produced annually. The domestically created EEE is combined with the damaged equipment that is delivered, thereby increasing the amount of waste electronic and electrical equipment's (WEEE) generated. The E-waste facility in Agbogbloshie is regarded as one of the largest E-waste sites as a result of these significant amounts of WEEE [49]. The handling of these e-wastes, including manual handling of lead-acid batteries, open burning of cables, and other methods, results in the release of significant amounts of heavy metals associated with e-waste, which end up in the Korle lagoon [46,47,49]. Generally, high concentrations of As, Hg, Cr, Cu, Pb, and Zn are associated with e-waste activities [50–53]. Mercury has a good electrical conduction and is mostly used in electrical and electronic switches [54]. Decharat, (2018) assessed the levels of mercury in the urine of E-waste workers and found a significant concentration of Hg in their urine. This supports our findings as these metals were found in the soils and vegetables used in our investigation. During times of high rainfall, the lagoon overflows into these farmlands, carrying the heavy metals with it. This agrees with the findings of [55] who observed that floods can remobilize heavy metals that have been deposited in riverbeds and floodplains. Similar to this, [56]; demonstrated how heavy metals in floodwater are transferred to the soil and then absorbed by crops. According to Ref. [57]; a significant flood event could potentially increase the bioavailability of metals (particularly Pb) for crops in the majority of agricultural soils (66%), endangering human health. This observation is consistent with the fact that farms near the Korle lagoon contain significant levels of metals in their soil and vegetables cultivated on the lands.

The highest metal concentration in the soil and plants was found in lettuce. This agrees with the findings of [58]; who also showed significant levels of metals in lettuce. This is explained by the area proximity to the Korle lagoon. Due to the high concentration of metals in the Korle, places that are considerably closer to the Korle lagoon are prone to accumulate significant concentrations of heavy metals. According to Ref. [58]; surface soil near polluted sites had more metals than soils farther away. When vegetables are grown on this land, heavy metals are absorbed into the plant tissues and this makes the products unsafe for ingestion. When compared to other plant kinds, leafy vegetables are known to have a higher propensity to absorb heavy metals [59]. The findings of the study showed that there was significant bioaccumulation of heavy metals. It is possible that different processes are used in the uptake of heavy metals from the soil as indicated by a statistically significant difference between the Transfer factor for the various vegetables ($P = 0.004$; $P < 0.05$) and the various heavy metals examined ($P = 0.004$; $P < 0.05$). The amount of heavy metals in the soil where the vegetables were produced, the type of heavy metal, and the type of plant are all factors that affect how much metals are absorbed by plants [60]. Lettuce had the highest transfer factor. The high transfer factor of lettuce is consistent with the concentration of metals in the soil since the soil in which lettuce was grown had the highest concentration of metals. Despite having the lowest soil metal concentration, eggplant had the highest transfer factor after lettuce. This suggests that the Eggplant has a very high rate of heavy metal uptake from soil to plants as demonstrated by the transfer factors.

The transfer factors of heavy metals can be influenced by the pH of the medium. The pH exhibited significant loading in PC2, which accounted for 17% of the total variance. The bioavailability and absorption of heavy metals are significantly influenced by the pH of the soil (Kebeta- Pandais and Pandais, 2011). This is due to the fact that metals that are associated with the mobile fractions of the soil have a high bioavailability at low pH levels where there is less adsorption of metals to organic materials in the soil [61]. The pH adsorption edge, where the trend of trace metal adsorption increases from nearly little adsorption to total adsorption, occurs at intermediate pH [61]. Metals totally adsorb to organic particles at high pH levels, which lowers the bioavailability of certain metals [61]. Even though the pH of the soil was close to neutral and alkaline (7.5 and 8.47, respectively), the transfer factor seen for lettuce and eggplant from the Korle farm was high. However, this agrees with the finding of Krol et al., 2020 who reported high heavy metal mobility and bioavailability in soil with high pH (10). The properties of the soil's ionic species and its chemical processes, including pH, determines the fate of bioavailable heavy metals (Kebeta Pandais and Pandais, 2011). The eggplant is known to have high transfer factor and similar result was reported by Ref. [62]; who also observed that apart from the high transfer factor of Eggplant, there was also a high translocation factor from root to shoot. Eggplant can thus be described as a Metallophyte or hyperaccumulator that has the ability to uptake large amount of heavy metals from the soil. Unlike non-hyperaccumulator plants, hyperaccumulators of heavy metals do not retain the heavy metal absorbed in their roots but translocate them into shoots via xylem with the help of several proteins which also regulate metal homeostasis as well as their tolerance [63].

Heavy metal accumulation in agricultural foods provides a direct pathway into the food chain [17]; Vanisree et al., 2021). With the exception of Zn and Fe, which exceeded the recommended guidelines, most heavy metals were within the required WHO/FAO guidelines. The EDI, HQ, and HI were used to estimate the non-carcinogenic health risk. The amount of heavy metal exposure is closely related to daily intake (Jaishanker et al., 2014). In general, all vegetables had levels of metals that were within their recommended daily allowance. However, the estimated daily intake for lettuce was high for all metals, particularly for children, indicating that eating lettuce could have negative health effects due to the high levels of heavy metals. Similar to this, lettuce and eggplant also had high HQs. Hazard quotient only addresses specific heavy metals, whereas food samples may contain multiple metals. Calculating the hazard index, which considers each particular metal involved in risk assessment, becomes important. Except for onion and cauliflower for adults, every vegetable examined had a Hazard index that was higher than the recommended guideline limit of 1. It was observed that children were at a greater risk than adults.

Due to the rising cancer incidence, the carcinogenic risk connected with heavy metals is a concern globally. This is because the risk of cancer development can be enhanced by heavy metals [64]. The association between heavy metals and some cancer types has been shown in numerous recent research [65–67]. For instance, Adimalla et al. (2020), examined the relationship between heavy metals in soil and their health risks for adults and children in India and observed that high concentrations of arsenic and chromium may be linked to an increased risk of cancer in both adults and children [66]; assessed the relationship between food contaminated with heavy metals and the incidence and spatial distribution of stomach cancer in Hangzhou, China and found a significant association. According to a cross-sectional investigation of the tissue levels of trace elements carried out in Tehran, [68,69]; discovered evidence for the involvement of heavy metals in the development of colon cancer. Heavy metal exposure over an extended period of time is not advisable because of the adverse effects on health. The LCR of vegetables grown on land close to the Korle lagoon was evaluated. Due to the lack of a cancer slope factor at the time of assessment, Cu, As, Hg, and Fe were not evaluated. It is advised that LCR exceeding $1 \times 10^{-4}$ is detrimental and increases the risk of cancer. The LCR results for lettuce, eggplant, and amaranth suggest that there are cancer risks associated with the intake of these vegetables, however onion and cauliflower do not pose any carcinogenic health risk. Once more, it was observed that children were at a higher risk than adults.

## 7. Conclusion

In this study, the concentration of metals in vegetables from a farm within the catchment of the Korle Lagoon was estimated, and the health risks of exposure by ingestion were evaluated. In farm soil and vegetables, metal concentrations were exceptionally high. Eggplant (0.09–1.36) was shown to have a high rate of heavy metal uptake from the soil and may be suitable for bioremediation. Also, lettuce was found to contain extremely high concentration of heavy metals (0.02–3599.6 mg/kg). The Korle lagoon, which is known to be polluted with high concentration of heavy metals, was identified as the main sources of the heavy metal in this farmland. In general, the risk assessment showed that the food produced from land in the Korle catchment is unfit for human consumption and consuming such foods may increase the risk of developing cancer due to excessive Cr and Pb levels. As a result, it is not safe to conduct farming activities on lands closer to the Korle Lagoon. According to the risk assessment, both carcinogenic and non-carcinogenic health risks may be higher for children than for adults.

Residents in this region must take extra care with the food they eat. Government authorities must act decisively to address both the risk to public health from heavy metal pollution caused by human activities within the study area. The stricter implementation of environmental regulations regarding waste generation and discharges would be an efficient method in reducing heavy metal pollution. Before being released into the environment, waste must be treated. To lessen the influence on the environment, education should be provided regarding more effective ways to handle electronic waste. Stricter enforcement of the hazardous and electronic waste control and management act (Act 917) by the EPA which seeks to improve upon the collection, transport, and storage of electronic and electrical waste in the country will be effective in reducing the heavy metals levels in the study area.

## Author contribution statement

Richard Osae: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Daniel Nukpezah: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Daniel Amoako Darko; Samuel Senyo Koranteng; Adelina Mensah: Conceived and designed the experiments; Analyzed and interpreted the data.

## Data availability statement

Data included in article/supplementary material/referenced in article.

## 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.

## References

[1] A.A. Mohammadi, A. Zarei, M. Esmaeilzadeh, M. Taghavi, M. Yousefi, Z. Yousefi, F. Sedighi, S. Javan, Assessment of heavy metal pollution and human health risks assessment in soils around an industrial zone in Neyshabur, Iran, Biol. Trace Elem. Res. 195 (2020) 343–352.
[2] S. Singh, P. Parihar, R. Singh, V.P. Singh, S.M. Prasad, Heavy metal tolerance in plants: role of transcriptomics, proteomics, metabolomics, and ionomics, Front. Plant Sci. 6 (2016) 114. https://www.frontiersin.org/article/10.3389/fpls.2015.01143.
[3] O. Akoto, J.H. Ephraim, G. Darko, Heavy metals pollution in surface soils in the vicinity of abundant railway servicing workshop in Kumasi, Ghana, Int. J. Environ. Res. 2 (4) (2008) 359–364.
[4] I.A. Rather, W.Y. Koh, W.K. Paek, J. Lim, The sources of chemical contaminants in food and their health implications, Front. Pharmacol. 8 (2017) 830, https://doi.org/10.3389/fphar.2017.00830.
[5] A. Zwolak, M. Sarzyńska, E. Szpyrka, et al., Sources of soil pollution by heavy metals and their accumulation in vegetables: a review, Water Air Soil Poll. 230 (2019) 164, https://doi.org/10.1007/s11270-019-4221-y.
[6] M.M. Onakpa, A.A. Njan, O.C. Kalu, A review of heavy metal contamination of food crops in Nigeria, Ann. Glob. Health 84 (3) (2018) 488–494, https://doi.org/10.29024/aogh.2314.
[7] M. Gebrelibanos, N. Megersa, A.M. Taddesse, Levels of essential and non-essential metals in edible mushrooms cultivated in Haramaya, Ethiopia, Food Contam. 3 (2016) 2, https://doi.org/10.1186/s40550-016-0025-7.
[8] P.K. Rai, S.S. Lee, M. Zhang, Y.F. Tsang, K. Kim, Heavy metals in food crops: health risks, fate, mechanisms, and management, Environ. Int. 125 (2019) 365–385, https://doi.org/10.1016/j.envint.2019.01.067.
[9] I. Martorell, G. Perelló, R. Martí-Cid, J.M. Llobet, V. Castell, J.L. Domingo, Human exposure to arsenic, cadmium, mercury, and lead from foods in Catalonia, Spain: temporal trend, Biol. Trace Elem. Res. 14 (3) (2011) 309–322, 2011.
[10] A. Khan, S. Khan, M.A. Khan, Z. Qamar, M. Waqas, The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: a review, Environ. Sci. Pollut. Control Ser. 22 (18) (2015) 13772–13799, https://doi.org/10.1007/s11356-015-4881-0.
[11] T. Tongesayi, P. Fedick, L. Lechner, C. Brock, A. Beau, C. Bray, Daily bio accessible levels of selected essential but toxic heavy metals from the consumption of non-dietary food sources, Food Chem. Toxicol.: Int. J. Pub. Brit. Indus. Biolog. Res. Assoc. 62 (2013), https://doi.org/10.1016/j.fct.2013.08.052.
[12] C.T. Chasapis, A.C. Loutsidou, C.A. Spiliopoulou, M.E. Stefanidou, Zinc Human health: Update 86 (4) (2012) 521–534, https://doi.org/10.1007/s00204-011-0775-1.
[13] B. Zambelli, V. Uversky, S. Ciurli, Nickel impact on human health: an intrinsic disorder perspective, Biochim. Biophys. Acta, Proteins Proteomics 1864 (12) (2016) 1714–1731, https://doi.org/10.1016/j.bbapap.2016.09.008.
[14] M. Esmaeilzadeh, J. Jaafari, A.A. Mohammadi, M. Panahandeh, A. Javid, S. Javan, Investigation of the extent of contamination of heavy metals in agricultural soil using statistical analyses and contamination indices, Human Ecolog. Risk Assess. 25 (5) (2019) 1125–1136.
[15] Y. Vasseghian, S.S. Rad, J.A. Vilas–Boas, A. Khataee, A global systematic review, meta-analysis, and risk assessment of the concentration of vanadium in drinking water resources, Chemosphere 267 (2020), 128904.
[16] L. Jarup, L. Hellstrom, T. Alfvén, M.D. Carlsson, A. Grubb, B. Persson, C. Pettersson, G. Spång, A. Schütz, C.G. Elinder, Low level exposure to cadmium and early kidney damage: the OSCAR study, Occup. Environ. Med. 57 (10) (2000) 668–672.
[17] P.M. Rai, S.S. Lee, M. Zhang, Y.F. Tsang, K. Kim, Heavy metals in food crops: health risks, fate, mechanisms, and management, Environ. Int. 125 (2019) 365–385, https://doi.org/10.1016/j.envint.2019.01.067.
[18] M. Jaishankar, T. Tseten, N. Anbalagan, B.B. Mathew, K.N. Beeregowda, Toxicity, mechanism, and health effects of some heavy metals, Interdiscipl. Toxicol. 7 (2) (2014) 60–72, https://doi.org/10.2478/intox-2014-0009.
[19] D.A. Mengistu, Public health implications of heavy metals in foods and drinking water in Ethiopia (2016 to 2020): systematic review, BMC Publ. Health 21 (2021) 2114, https://doi.org/10.1186/s12889-021-12189-3.
[20] R.A. Fallahzadeh, S.A. Almodaresi, D. Ghadirian, A. Fattahi, Spatial analysis and probabilistic risk assessment of exposure to nitrate in drinking water of Abarkouh, Iran J. Health Sustain. Develop. 4 (2) (2019) 744–752.
[21] A. Karikari, K. Asante, C. Biney, Water quality characteristics at the estuary of Korle lagoon in Ghana, West Afr, J. Appl. Ecol. 10 (1) (2009), https://doi.org/10.4314/wajae. v10i1.45700.
[22] B. Fosu-Mensah, E. Addae, D. Yirenya-Tawiah, F. Nyame, Heavy metals concentration and distribution in soils and vegetation at Korle Lagoon area in Accra, Ghana, Cogent Environ. Sci. 3 (2017), https://doi.org/10.1080/23311843.2017.1405887.
[23] B.L. Kawatra, P. Bakhetia, Consumption of heavy metal and minerals by adult women through food in sewage and tube-well irrigated area around Ludhiana city (Punjab, India), J. Hum. Ecol. 23 (2008) 351–354.
[24] W. Haiyan, A. Stuanes, Heavy metal pollution in air-water-soil-plant system of Zhuzhou city, Hunan province, China. Water, Air Soil Poll. 147 (2003) 79–107, https://doi.org/10.1023/A:1024522111341.
[25] A. Walkley, I.A. Black, An examination of the Degtjar method for determination of soil organic matter and a proposed modification of the chronic acid titration method, Soil Sci. 37 (1) (1934) 29–38.
[26] U.S. EPA, Method 3050B: Acid Digestion of Sediments, Sludges, and Soils," Revision 2, 1996 (Washington, DC).
[27] S.R. Taylor, Abundance of chemical elements in the continental crust: a new table, Geochem. Cosmochim. Acta 28 (8) (1964) 1273–1285.
[28] G. Müller, The heavy metal pollution of the sediments of neckars and its tributary: a stocktaking, Chem. Ztg. 105 (1981) 157–164.

[29] J.E. Emurotu, P.C. Onianwa, Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, north central Nigeria, Environ. Sys. Res. 6 (2017) 21, https://doi.org/10.1186/s40068-017-0098-1.

[30] USEPA (United States Environmental Protection Agency), *EPA Region III Risk-Based Concentration (RBC) Table 2008 Region III*, 1650 Arch Street, Pennsylvania, Philadelphia, 2012, 19103.

[31] USEPA (United States Environmental Protection Agency), Office of Water Regulations and Standard: *Guidance Manual for Assessing Human Health Risks from Chemically Contaminated, Fish and Shellfish*, U.S. Environmental Protection Agency, Washington, DC, 1989. EPA-503/8-89-002.

[32] WHO/FAO, Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty-Eight Session of the Codex Committee on Food Hygiene, United States of America, Houston, 2007. ALINORM 07/30/13.

[33] P. Marina, M. Snežana, N. Maja, M. Miroslava, Determination of heavy metal concentration and correlation analysis of turbidity: a case study of the zlot source (bor, Serbia), Water Air Soil Poll. 231 (2020) 98, https://doi.org/10.1007/s11270-020-4453-x.

[34] T. Ahmad, K. Ahmad, Z.I. Khan, Z. Munir, A. Khalofah, R.N. Al-Qthanin, M.S. Alsubeie, S. Alamri, M. Hashem, S. Farooq, M.M. Maqbool, S. Hashim, Y.F. Wang, Chromium accumulation in soil, water and forage samples in automobile emission area, Saudi J. Biol. Sci. 28 (6) (2021) 3517–3522, https://doi.org/10.1016/j.sjbs.2021.03.020.

[35] Lough, G.C., Schauer, J.J., Park, J.S., Shafer, M.M., Deminter, J.T., Weinstein, J.P., Emissions of metals associated with motor vehicle roadways. Environ. Sci. Technol. 1;39(3):826-836. doi: 10.1021/es048715f. PMID: 15757346.

[36] Wang, J.M., Jeong, C., Hilker, N., Healy, R.M., Sofowote, U., Debosz, J., Su, Y., Munoz, A., Evans, G.J. Environ. Poll., 268,https://doi.org/10.1016/j.envpol.2020.115805.

[37] Y. Cheng, S.C. Lee, K.F. Ho, J.C. Chow, J.G. Watson, P.K.K. Louie, J.J. Cao, X. Hai, Chemically-speciated on-road PM2.5 motor vehicle emission factors in Hong Kong, Sci. Total Environ. 408 (7) (2010) 1621–1627, https://doi.org/10.1016/j.scitotenv.2009.11.061.

[38] Mahta Talebzadeh, Caterina Valeo, Rishi Gupta, Cadmium Water Pollution Associated with Motor Vehicle Brake Parts. CEESD 2020 International Conference on Environmental Engineering and Sustainable Development, 2020 (China).

[39] H. Naser, S. Sultana, R. Gomes, S. Noor, Heavy metal pollution of soil and vegetable grown near roadside at gazipur, Bangladesh J. Agric. Res. 37 (2012), https://doi.org/10.3329/bjar.v37i1.11170.

[40] M. Malakootian, A. Mohammadi, A. Nasiri, C.G. Oliveri, M. Faraji, Correlation between heavy metal concentration and oxidative potential of street dust, Air Qual. Atmos. Health 15 (4) (2022) 731–738, https://doi.org/10.1007/s11869-021-01130-7.

[41] R. Osae, D. Nukpezah, D.D. Amoako, A. Mensah, Heavy metal mobility, bioavailability, and potential toxicity in sediments of the Korle lagoon in Ghana, Int. J. Environ. Stud. (2022), https://doi.org/10.1080/00207233.2022.2042971.

[42] C.A. Clottey, Assessment of the Physichochemical Parameters and Heavy Metal Contamination in Korle and Kpeshie Lagoon, Master Thesis, institute of environmental and sanitation studies, University of Ghana, Legon, 2018.

[43] H.R. Aboagye, Heavy Metal Concentration in Flesh of Boe Drum (Pteroscion Peli) and Greater Amberjack (Seriola Dumerelli) from the Korle Lagoon Estuary, Accra Ghana. Master Thesis, College of Agricultural and Natural Resources, Department of fisheries and water shed management, Kwame Nkrumah University of Science and Technology, 2012.

[44] K. Boadi, M. Kuitunen, Urban waste pollution in Korle lagoon, Environmentalist 22 (2002) 301–309.

[45] S.L. Steinhausen, N. Agyeman, P. Turrero, A. Ardura, E. Garcia-Vazquez, Heavy metals in fish nearby electronic waste may threaten consumer's health. Examples from Accra, Ghana, Mar. Pollut. Bull. 175 (2022), 113162, https://doi.org/10.1016/j.marpolbul.2021.113162. Epub 2021 Nov 25. PMID: 34839955.

[46] K. Daum, J. Stoler, R.J. Grant, Toward a more sustainable trajectory for E-waste policy: a review of a decade of E-waste research in accra, Ghana, Int. J. Environ. Res. Publ. Health 14 (2017) 135, https://doi.org/10.3390/ijerph14020135.

[47] B.K. Sovacool, Toxic transitions in the lifecycle externalities of a digital society: the complex afterlives of electronic waste in Ghana, Resour. Pol. 64 (2019) a101459. ISSN 0301-4207.

[48] M. Oteng-Ababio, Electronic waste management in Ghana - issues and practices, in: Sustainable Development - Authoritative and Leading-Edge Content for Environmental Management. IntechOpen, 2012, https://doi.org/10.5772/45884.

[49] K. Owusu-Sekyere, A. Batteiger, R. Afoblikame, G. Hafner, M. Kranert, Assessing data in the informal e-waste sector: the Agbogbloshie Scrapyard, Waste Manag. 139 (2022) (2022) 158–167, https://doi.org/10.1016/j.wasman.2021.12.026.

[50] D. Nukpezah, H.A. Okine, M. Oteng-Ababio, B.D. Ofori, Electronic waste risk assessment and management in Ghana, in: J.M. Gómez, M. Sonnenschein, U. Vogel, A. Winter, B. Rapp, N. Giesen (Eds.), Proceedings of the 28th EnviroInfo 2014 Conference, 2014, pp. 205–212. Oldenburg, Germany.

[51] A. Pascale, A. Sosa, C. Bares, A. Battocletti, M.J. Moll, D. Pose, A. Laborde, H. Gonzalez, G.E. Feola, Waste informal recycling: an emerging source of lead exposure in south America, Ann. Glob. Health 82 (2016) 197–201, https://doi.org/10.1016/j.aogh.2016.01.016.

[52] V.N. Kyere, K. Greve, S.M. Atiemo, Spatial assessment of soil contamination by heavy metals from informal electronic waste recycling in Agbogbloshie, Ghana, Environ. Health Toxicol. 31 (2016), e2016006, https://doi.org/10.5620/eht.e2016006.

[53] L. Neeratanaphan, S. Khamma, R. Benchawattananon, P. Ruchuwararak, S. Appamaraka, S. Intamat, Heavy metal accumulation in rice (Oryza sativa) near electronic waste dumps and related human health risk assessment, Hum. Ecolog. Risk Assess. 23 (2017) 1086–1098, https://doi.org/10.1080/10807039.2017.1300856.

[54] L.O. Amponsah, P.B. Sørensen, M.A. Nkansah, et al., Mercury Contamination of Two E-Waste Recycling Sites in Ghana: an Investigation into Mercury Pollution at Dagomba Line (Kumasi) and Agbogbloshie (Accra), Environmental Geochemistry Health, 2022, https://doi.org/10.1007/s10653-022-01295-9.

[55] Y. Zhao, S.B. Marriott, Dispersion and remobilization of heavy metals in the river severn system, UK, Proced. Environ. Sci. 18 (2013) 167–173, https://doi.org/10.1016/j.proenv.2013.04.022.

[56] T. Ciesielczuk, G. Kusza, J. Poluszyńska, K. Kochanowska, Pollution of flooded arable soils with heavy metals and polycyclic aromatic hydrocarbons (PAHs), Water Air Soil Pollut. 225 (10) (2014) 2145, https://doi.org/10.1007/s11270-014-2145-0.

[57] J. Marrugo-Negrete, J. Pinedo-Hernández, E.M. Combatt, A.G. Bravo, S. Díez, Flood-induced Metal Contamination in the Topsoil of Floodplain Agricultural Soils: a Case-Study in Colombia, Land Degradation & Development, 2019, pp. 1–11, https://doi.org/10.1002/ldr.3398.

[58] R. Ferri, F. Donna, D.R. Smith, S. Guazzetti, A. Zacco, L. Rizzo, E. Bontempi, N.J. Zimmerman, R.G. Lucchini, Heavy metals in soil and salad in the proximity of historical ferroalloy emission, J. Environ. Protect. 3 (5) (2012) 374–385, https://doi.org/10.4236/jep.2012.35047.

[59] H.H.A. Mohamed, M.A. Khairia, Assessment of some heavy metals in vegetables, cereals and fruits in Saudi Arabian markets, Egyp. J. Aqu. Res. 38 (1) (2012) 31–37, https://doi.org/10.1016/j.ejar.2012.08.002.

[60] N. Mirecki, R. Agic, L. Šunić, L. Milenkovic, Z. Ilic, Transfer factor as indicator of heavy metals content in plants, Fresenius Environ. Bull. 24 (2015) 4212–4219.

[61] H.B. Bradl, Adsorption of heavy metal ions on soils and soils constituents, J. Colloid Interface Sci. 277 (1) (2004) 1–18, https://doi.org/10.1016/j.jcis.2004.04.005.

[62] Mohamed Youssef, Accumulation and translocation of heavy metals in eggplant (solanum melongena L.) grown in a contaminated soil, J. Ener. Environ. Chem. Eng. 3 (2018) 9, https://doi.org/10.11648/j.jeece.20180301.12.

[63] A. Singh, P. Parihar, R. Singh, S.M. Prasad, An assessment to show toxic nature of beneficial trace metals: too much of good thing can be bad, Int. J. Curr. Multidisc. Stud. 2 (2016) 141–144.

[64] S. Cao, X. Duan, X. Zhao, J. Ma, T. Dong, N. Huang, C. Sun, B. He, F. Wei, Health risks from the exposure of children to As, Se, Pb and other heavy metals near the largest coking plant in China, Sci. Total Environ. 472 (2014) 1001–1009.

[65] N. Adimalla, Heavy metals pollution assessment and its associated human health risk evaluation of urban soils from Indian cities: a review, Environ. Geochem. Health 42 (2020) 173–190, https://doi.org/10.1007/s10653-019-00324-4.

[66] X. Fei, Z. Lou, G. Christakos, Z. Ren, Q. Liu, X. Lv, The association between heavy metal soil pollution and stomach cancer: a case study in Hangzhou City, China, Environ. Geochem. Health 40 (6) (2018) 2481–2490, https://doi.org/10.1007/s10653-018-0113-0.

[67] L. Qiao, Y. Feng, Intakes of heme iron and zinc and colorectal cancer incidence: a meta-analysis of prospective studies, Cancer Causes Control 24 (6) (2013) 1175–1183, https://doi.org/10.1007/s10552-013-0197-x, 2013.

[68] M. Sohrabi, A. Gholami, M.H. Azar, M. Yaghoobi, M.M. Shahi, S. Shirmardi, et al., Trace element and heavy metal levels in colorectal cancer: comparison between cancerous and non-cancerous tissues, Biol. Trace Elem. Res. 183 (1) (2018) 1–8, https://doi.org/10.1007/s12011-017-1099-7.

[69] N. Jafarzadeh, K. Heidari, A. Meshkinian, H. Kamani, A.A. Mohammadi, G.O. Conti, Non-carcinogenic risk assessment of exposure to heavy metals in underground water resources in Saraven, Iran: spatial distribution, monte-carlo simulation, sensitive analysis, Environ. Res. 204 (2022), 112002, https://doi.org/10.1016/j.envres.2021.112002.