Pollution Characteristics, Source Identification, and Health Risk of Heavy Metals in the Soil-Vegetable System in Two Districts of Bangladesh

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Abstract

The consequences of climate change, food security, and self-sufficiency goals are driving excessive human activity onto vegetable farms in Bangladesh, and harmful heavy metal exposure is spreading. So, the study assessed the toxic metals (Pb, Cd, and Cr) exposure, characteristics, and human health risk regarding the soil-vegetable system of two distinct locations in Bangladesh using atomic absorption spectrometry. The average concentration of metals in soil and fertilizer/pesticide samples followed the same order (Cr > Pb > Cd), but for vegetable samples, the order was Pb > Cr > Cd, with some extra Pb compared to the World Health Organization (WHO) allowable limit (0.3 mg/kg). Low levels of pollution with negligible ecological concerns were predicted for both locations by the soil quality indexing. But industrial influence boosted the Pb content in location B, and common sources (fertilizer/pesticide) for both locations might be responsible for a moderate level of Cd. The toxic metals transferred to vegetables followed the trend of Cd > Pb > Cr. However, the human health risks arising from harmful metals exposure at both locations were ineffective (< 1) in evaluating noncarcinogenic risk patterns through the target hazard quotient (THQ), total THQ, and hazard index (HI). Again, considering probable carcinogenic risk patterns, vegetable consumption with studied exposure levels of toxic metals followed within the acceptable range (between 1.0E-04 and 1.0E-06). Overall, location B is slightly more vulnerable than location A by considering metal exposure, pollution distribution, and risk evaluation in the study area (significant at $p < 0.05$). So, systematic monitoring and protective measures are required to ensure food safety and sustainable vegetable production.

Keywords Toxic heavy metals · Soil-vegetable system · Quality indexes · Industrial area · Nonindustrial area · Health risk assessment

Introduction

Vegetables contain a wide variety of micronutrients that are essential for human health. Scientific evidence shows that vegetables have enormous health benefits for those who consume sufficient quantities [1]. However, human feeding habits are responsible for about 33% of cancer-related health consequences and about 50% of cardiovascular problems [2]. Biologically active micronutrients in vegetables have antioxidants, anticarcinogens, and anti-immunological effects

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on the human body. In addition, it provides essential vitamins, minerals, and dietary fiber to the human body [2–5]. The physical and chemical properties of micronutrients in vegetables, along with their medicinal and protective properties, denote a source of nutraceuticals and phytonutraceuticals [3, 4, 6]. Observe, for instance, that (a) ascorbic acid is found in almost all vegetables and has therapeutic effects on cardiovascular disease and immunity [3]; (b) alpha- and beta-carotenes are found in almost all vegetables and offer protection from diabetes, coronary artery disease, cancer, and night blindness [3]; (c) dietary fiber in vegetables helps to prevent diabetes, heart disease, and colorectal cancer; and (d) folates in dark green vegetables like spinach and broccoli have potential health benefits including improving fertility and preventing cancer and heart disease [3, 4]. Even so, several studies found that a healthy plant-based diet could reduce coronavirus development and severity [7, 8]. Thus, in the new normal situation of the world, the interest in vegetables in the human diet has increased (27%) worldwide [7]. Globally, health authorities like the WHO promote sufficient intake of vegetables, recommending 220 g of vegetables per person per day [9].

Soil health management plays a critical role in the sustainable supply of micronutrients in vegetables and other agri-food systems. Recently, experts and regulators have imposed several innovative ways to sustain soil health, like the application of nanotechnology, foliar fertilization, organic farming, fertilizer variation, carbon regeneration, and crop rotation, in different parts of the world [10–13]. However, soil health management is challenging because of the difficulty of recording the inflow and outflow of nutrients in the soil [10, 14]. So the most dependable and proven way to sustain a soil's nutrient cycle is the controlled imposition of fertilizer on farmland. It is the best way to produce a quality yield of vegetables and other crops [16–18]. Chemical fertilizers mainly contain phosphate, nitrate, ammonium, and potassium salts [18]. In developing countries with densely populated areas, such as Bangladesh, conventional chemical fertilizers are regularly supplied to farms, patronized by the government, to increase commercial yield [14, 19]. Between 1971 and 2020, fertilizer consumption in Bangladesh grew substantially from 12.9 to 320.9 kg/ha [20]. In 2020, fertilizer utilization for Bangladesh was 320.9 kg/ha, which is much more than different countries like Turkey (100.4 kg/ha), China (301.5 kg/ha), Britain (287.5 kg/ha), Germany (205.4 kg/ha), France (180.1 kg/ha), the USA (160.8 kg/ha), Italy (126.4 kg/ha), India (121.4 kg/ha), Greece (115.4 kg/ha), and Indonesia (106.9 kg/ha) [18]. Besides this, the excessive and improper use of traditional fertilizers has a widespread detrimental effect on the ecosystem [19, 21–24]. The commercial fertilizer also contained substantial amounts of toxic metals and could contribute to the accumulation of toxic metals such as lead, cadmium, arsenic, chromium, and radioactive elements in the soil [17, 18, 21, 23, 25]. Accordingly, it decreases the nutrient density of consumed plants [23]. Aside from this, pesticides are taking over the world to ensure the quality of vegetables and other agro-crops to increase their yield, thus ensuring food security [14, 26, 27]. Approximately 3 billion kilograms of pesticides are used worldwide annually, with a yearlong increase of 11% [26]. Farmers in Bangladesh use pesticides extensively on high-demand, quickly degradable crops like vegetables and fruits [28]. But the worst part is that it might carry significant amounts of toxic heavy metals that contaminate vegetables and other edible agro-foods [5, 26, 29]. However, several sources of elements or components, such as climate change, unwanted seasonal variation, excessive use of fertilizer and pesticides, industrial effluent, electronic waste, man-made waste, and poor management of agricultural land [30–34] that influence or hamper the balance of the nutrient cycle, affect overall soil health and plant nutrients [15].

Currently, toxic heavy metals' integration into the soil system, at a threatening level, gradually hampers food health as well as the human body by affecting soil biology [21, 35]. The translocation of heavy metals from soil to plants maintained a dynamic equilibrium using the soil's physical, chemical, and biological properties [25, 36]. So, the toxic metals can smoothly accumulate from the soil systems to the plants' roots and shoots. However, rapid urbanization, industrialization, and climate change issues in the last 30–40 years of the history of Bangladesh have remarkably decreased the agricultural land [13, 14, 34]. During this time, hybrid seed use with unbalanced fertilizer and pesticide practices expands rapidly to ensure food self-sufficiency. Therefore, farmed soil is now facing severe environmental health risks due to toxic metal exposure [13, 14]. The cultivation of vegetables in contaminated soil might pose a threat to the human body. Again, the uptake of vegetables containing heavy metals over the permissible limit is the ultimate risk to human health [37]. The undesirable heavy metals then have harmful effects after several years of exposure. The deleterious effects can be noncarcinogenic or carcinogenic based on heavy metal exposure to the human body [37]. Now the utmost concentration is that it has not found any complete systematic study regarding industrial and nonindustrial aspects of heavy metal contamination in vegetable farmland in Bangladesh. Also, it has not yet seen any examination of heavy metal levels against the fertilizers/pesticides used on farmland in Bangladesh. But plenty of investigation has been done for other sources, like irrigation water. So the analysis of this source (fertilizers/pesticides) with the industrial and nonindustrial aspects of heavy metal contamination in vegetable farmland is urgently needed to guide sustainable vegetable production and food safety issues. In addition,

soil quality indexing for harmful metal exposure is required to track any ecological risk in industrial and nonindustrial areas. Finally, human health risk implications due to the consumption of vegetables in industrial and nonindustrial regions need to be assessed urgently.

Materials and Methods

Study Area and Sampling Location

The most cultivated vegetable-producing regions of Bangladesh, such as Bogura District (location A), which is situated in the northwestern part of the country, are considered the nonindustrial region, and Narsingdi District (location B), which is situated in the middle of the country and very close to the capital city of Bangladesh, Dhaka, is considered the industrial region. These regions were chosen as study areas. Because the northwest region of Bangladesh represents much less industrial activity, the Bogura District is much more popular for vegetable production in this region. Again, Dhaka and the areas around it are considerably more industrialized than other areas, and Narsingdi produces a lot of vegetables in this area. Six sampling sites were selected

for each location to collect soil, chemical fertilizers/ pesticides, and vegetables (Fig. 1).

Samples and Elements Selection

Six different types of vegetables (the most common and widely consumed by all levels of the population) were chosen for sampling in both regions as part of this study: potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), flat green bean (*Phaseolus vulgaris*), brinjal (*Solanum melongena*), cauliflower (*Brassica oleracea*), and green chili (*Capsicum annuum*). The chemical fertilizers and pesticides used during vegetable cultivation were intended to be collected as a sample. The subsurface soil (5–15 cm) of vegetable farmland was selected for analysis. For each site, 2 (two) samples of vegetable cultivated soil, 2 (two) samples of vegetables, and a minimum of 2 (two) samples of chemical fertilizer/pesticide used in vegetable cropping were chosen for the study to ensure the level of heavy metals. A total of 12 soils, 12 vegetables, and 12 fertilizer/pesticide samples were assumed to be collected from each location. The most harmful three heavy metals for human health hazards, like lead (Pb), cadmium (Cd), and chromium (Cr), were selected to assess their source investigation, quality indexing of soil, any possible bioaccumulation, and human health risk.

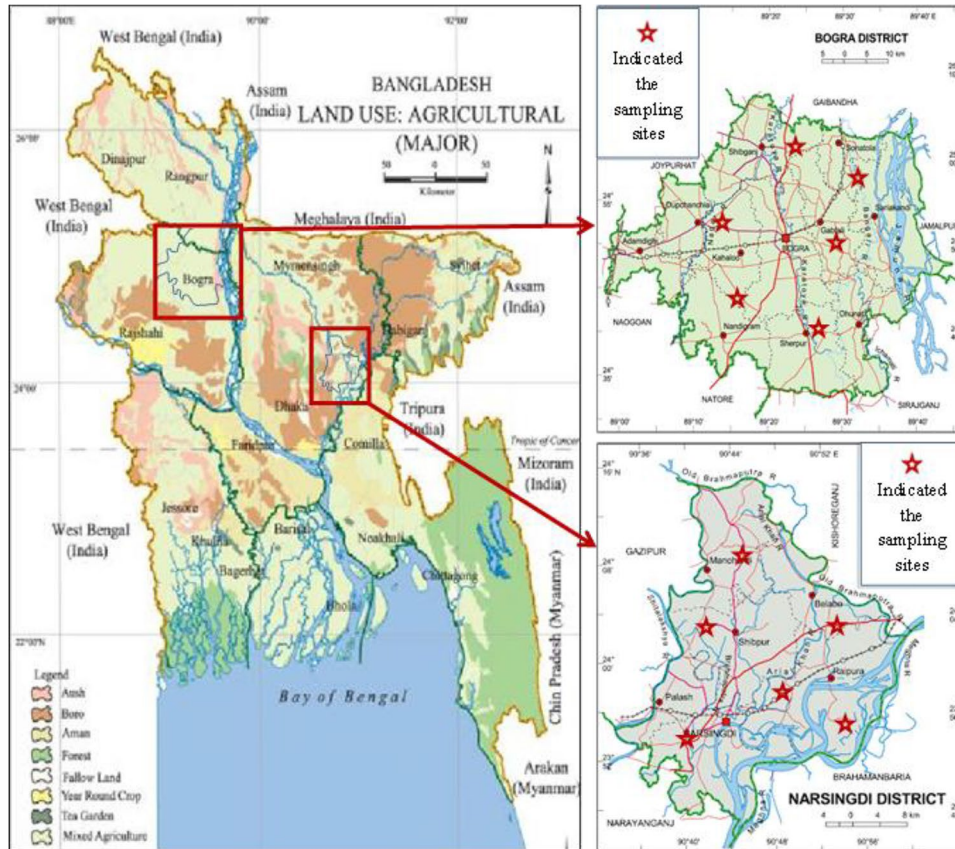Fig. 1 Illustrates the sampling locations in the study

Table 1 The laboratory recovery performances of CRMs were used in the method validation process

CRM	Element	Recommended value (mg/kg)	Laboratory mean concentration (mg/kg)	SD	Recovery (%)	RSD (%)	Uscore [56]
IAEA-433 (marine sediment)	Pb	28.0 ± 2.7	26.51	1.68	94.68	1.64	0.47
	Cd	0.153 ± .033	0.14	0.02	90.85	4.60	0.38
	Cr	136 ± 10	128.78	14.88	94.69	2.11	0.40
IAEA-359 (cabbage)	Pb	–	–	–	–	–	–
	Cd	0.115–0.125	0.13	0.01	105.00	6.29	0.70
	Cr	1.24–1.36	1.21	0.12	93.08	2.74	0.67

Collection, Preservation, and Processing of Samples

A minimum of 500 g of samples of each matrix were collected from the mentioned locations during the winter season. Soil and chemical fertilizer or pesticide samples were collected during the harvesting of vegetable samples. The samples were wrapped in a ziplock polythene bag to transport to the laboratory. To remove dirt or other fouling substances, vegetable samples were washed with distilled water immediately after shipment to the laboratory and then rewashed with DI water. The edible parts of each specimen were removed and chopped into pieces with the help of a cleaned stainless steel knife, and then, the samples were quantified. After that, the samples were heated in ovens at 100 °C until fully dehydrated, which was achieved by reaching a constant weight. We then measured the moisture content of the vegetables by weighing the dry sample. Also, the dried samples were ground into a fine powder through an agate mortar and stored in a new polythene bag, ready for digestion. Again, moist soil and fertilizer samples were taken in a previously weighed (oven-dehydrated) petri dish of around 5 g. The moist soil in the petri dish was then dried in a drying oven at 105 °C for several hours. The oven-dried samples were ground into a fine powder through an agate mortar and stored in a desiccator for digestion. The chemical pesticide samples did not require any preprocessing before digestion. Laboratory-developed standard methods were used for sample processing.

Sample Digestion

In this study, a laboratory-developed standard method using a hot plate was performed to digest soil, fertilizer/pesticides, and vegetable samples. The samples of 1–2 g of dry vegetables, 0.5 g of dry soil, and 1–2 g of fertilizer/pesticides were placed in a 100-ml beaker. Afterwards, the nitric acid (8–12 ml) (analytical grade, 65%) was poured into the glass beaker of vegetable and fertilizer/pesticide samples, but the soil samples were digested through 10 ml of aqua regia. A watch glass was placed at the mouth of the beaker, and then, the beakers were settled on a hot plate. The mixture was heated for a minimum of 8 h to remove all oxidizable matter. Then 1 ml of hydrogen peroxide (30%) was added to the vegetable samples, and the temperature was maintained for another 30 min. The digestion process was completed once all samples were dissolved in the acid, and the volume content was reduced to 1–2 ml. The digested solutions were filtered using filter paper with the addition of DI water and stored in a 25-ml vial. During the digestion process, a total of six blanks, six duplicates, and six spike samples were also digested side by side.

Instrumental Setup

The detection of Pb, Cd, and Cr in vegetable samples as well as Cd in soil and fertilizer/pesticide samples was done using a Varian AA280Z atomic absorption spectrometer (AAS) with a Zeeman background correction system equipped with a graphite furnace (GTA 120) and an autosampler (PSD 120). A Varian AA240FS atomic absorption spectrometer in flame mode was used to measure the amounts of Pb and Cr in soil and fertilizer/pesticide samples. The daily preparation of the working standard solutions involved the required dilution of the corresponding 1000 mg/L stock standard solutions using 1% (w/w) supra-pure grade nitric acid (Merck, Darmstadt, Germany). The instruments for analyzing soil, fertilizer/pesticides, and vegetables were used in conjunction with the validated methodologies (using SRM of vegetable and soil-based matrixes).

Quality Control and Quality Assurance of Controlled Methods

The quality assurance of this analysis was of the utmost importance. Due to this, the used techniques were created through a validation procedure utilizing relevant certified reference materials (CRMs), and they were then approved as meeting ISO/IEC 17,025:2017 criteria. The recovery performances of CRMs is presented in Table 1.

Additionally, all experimental facilities and the surrounding environment were kept up to ISO standards. All required glassware was thoroughly cleaned with DI water after being immersed in 20% nitric acid (6 M) for 24 h. For the soil, vegetable, and fertilizer/pesticide analyses, the blank, repeat, and spike samples showed outstanding recovery performance (between 90 and 110%) with high accuracy and precision (RSD within 10%). All samples and diluted standard solutions were examined in triplicate for each analyte, and an average RSD value of no more than 10% was considered acceptable. In every analysis, the quality control (QC) samples were run at regular intervals. During the method validation procedure, the limit of detection (LOD) was fixed. Additionally, a control chart was kept for each analysis to monitor variations from the QC baseline. Using GF-AAS, the LOD for Pb, Cd, and Cr was established, and it was discovered to be 0.06, 0.001, and 0.05 mg/kg, respectively, for the vegetable matrix. For soil and fertilizer matrices, the LOD for Pb and Cr was determined using F-AAS to be 0.2 and 0.15 mg/kg, respectively, while for Cd, it was determined using GF-AAS to be 0.001 mg/kg. It was to guarantee that the working procedure was of a high standard overall.

Calculation of Soil Quality Indexes

Geo-Accumulation Index (Igeo)

The geo-accumulation index (Igeo) is an assessment of the levels of heavy metal pollution in agricultural soil. Igeo values help divide soil into quality classes. I_{geo} values for metals are determined using the following expression [40, 41]:

$$I_{geo} = log_2[\frac{C_n}{1.5B_n}] \tag{1}$$

where C_n concentration of individual heavy metals and B_n value of geochemical background of corresponding metals. The background concentrations of Pb, Cd, and Cr found to be 20, 0.03, and 90 mg/kg, respectively [40]. The I_{geo} values are categorized as Igeo < 0, 0 < Igeo < 1, 1 < Igeo < 2, 2 < Igeo < 3, 3 < Igeo < 4, 4 < Igeo < 5, and 5 < Igeo with denoting a pollution class: practically uncontaminated, uncontaminated to moderately uncontaminated, moderately contaminated, moderately to heavily contaminated, heavily contaminated, heavily to extremely contaminated, and extremely contaminated, respectively [40].

Enrichment Factor (EF)

The enrichment factor (EF) enables the assessment of soil contamination sources by considering the content of heavy metals and the value of reference metals in relation to their background values. Elements such as Sr, Mn, Ti, Al, and Fe are usually chosen as references [42]. Fe is taken as a reference in this study. The general form of calculating EF is represented by the following equation [38, 42]:

$$EF = \left[\frac{C_n}{C_{ref}}\right]/[\frac{B_n}{B_{ref}}] \tag{2}$$

where C_n represents the concentrations of heavy metals in soil and C_{ref} represents the concentration of reference metal in the same area. B_n represents the geochemical background of studied heavy metals, and B_{ref} represents the background value of the reference metal that was found to be 47,200 mg/kg [52]. The enrichment factor range of $0.05 \leq EF \leq 1.5$ shows that toxic metals come from natural sources, but an enrichment factor greater than 1.5 indicates the anthropogenic source of heavy metals [38]. Again, EFs of 1.5–3, 3–5, 5–10, and > 10 are considered evidence of minor, moderate, severe, and very severe modification, respectively [38].

Contamination Factor (C_f^i)

The contamination factor is defined as the proportion of the heavy metal concentration in the soil ($C_{toxicmetal}$) to that of baseline or background value ($C_{background}$) as follows:

$$C_f^i = \frac{C_{toxicmetal}}{C_{background}} \tag{3}$$

The background values of Cr, Cd, and Pb in soil were recorded at 90, 0.3, and 20 mg/kg, respectively [40]. The C_f^i is separated into four different classes based on their contamination levels, ranging from 1 to 6, where $C_f^i < 1$ is denoted as low degree, $1 \leq C_f^i < 3$ as moderate degree, $3 \leq C_f^i < 6$ as considerable degree, and $6 \leq C_f^i$ is indicated as very high degree [40].

Pollution Load Index (PLI)

The PLI is also used to assess the overall level of contamination in soil. PLI is determined as the nth root of the product of the n-contamination factor (CF) [38] as follows:

$$PLI = \sqrt[n]{C_f^1 \times C_f^2 \dots C_f^n} \tag{4}$$

where C_f^1 contamination factor of element 1, C_f^2 contamination factor of element 2, and C_f^n contamination factor of the nth element. The PLI levels of < 0–0, 0–1, 1–2, 2–4, 4–8, and 8–16 represent no degree of pollution, a low degree of pollution, a moderate degree of pollution, a high degree of pollution, a very high degree of pollution, and an extremely high degree of pollution, respectively [38].

Potential Ecological Risk (PER) Index

The potential ecological risk is an index applicable for the assessment of the degree of ecological risk caused by heavy metal concentrations in the soil and is assessed by the following equations [42]:

$$E_r^i = T_r^i \times C_f^i \tag{5}$$

$$PERI = \sum_i^m E_r^i \tag{6}$$

The E_r^i represents the ecological toxicity risk of a given pollutant, and the PERI represents the integrated risk of toxicity of all considered pollutants; T_r^i is the toxicity coefficient of a heavy metal element, and C_f^i is the contamination factor of a heavy metal element. The toxicity coefficient for Cd, Cr, and Pb was recorded as 30, 2, and 5, respectively [48]. The E_r^i levels of < 40, $40 \leq E_r^i < 80$, $80 \leq E_r^i < 160$, and $160 \leq E_r^i < 320$ and PERI levels of < 150, $150 \leq RI < 300$, $300 \leq RI < 600$, and $RI \geq 600$ represent a low risk, a moderate risk, a considerable risk, and a high risk, respectively [38].

Bioaccumulation Factor

The bioaccumulation factor (BAF) is defined as the ratio of heavy metal concentration in edible part of a vegetable to heavy metal concentration in a soil sample [43]. The heavy metal transfer from soil to vegetables is calculated using the following equation [32]:

$$BAF = \frac{C_{plant}}{C_{soil}} \tag{7}$$

where C_{plant} is the heavy metal content in the edible part of a vegetables and C_{soil} is the heavy metal content in the respective soil on a dry weight basis. The presence of BAF values greater than one indicates that the plant accumulated a significant amount of the toxic metal, which must be considered in further analysis [35].

Calculation of Human Health Risk Assessment

Estimated Daily Intake (EDI)

Estimated daily intakes (EDIs) of lead, cadmium, and chromium are calculated using their average concentrations in vegetable samples, and the weight of vegetable items consumed by an individual (an average body weight of 60 kg for an adult in Bangladesh), which were obtained from the dietary guidelines for Bangladesh [39], is calculated by the following formula [35]:

$$EDI = \frac{Ef \times ED \times FI \times MC \times Cf}{BW \times AT \times 1000} mg/kg/day \tag{8}$$

where Ef is the exposure frequency (365 days per year), ED is the exposure duration (70 years) (the average life span is 70 years for both sexes for Bangladeshis) [50], FI is the food ingestion (g/person/day), MC is the metal concentration in vegetables (mg/kg, on a dry weight basis), Cf is the conversion factor (0.085) for vegetables fresh to dry weight [35, 44], BW is the average body weight (60 kg), and AT is the averaging time for noncarcinogens (365 days/year × number of exposure years, assuming 70 years in this study) [35]. FI for vegetables was documented at 167.30 g for 60 kg of body weight for adult Bangladeshis, which was obtained from the household income and expenditure survey (HIES, 2016) [50].

Noncarcinogenic Health Risk

In this study, the non-cancer health risks associated with the consumption of vegetables by local users are assessed based on target hazard quotients (THQs) and are computed by the following equations [45]:

$$THQ = \frac{EDI}{RfD} \tag{9}$$

In this study, cumulative health risk is assessed by combining the THQ values of each metal for respective vegetables and expressing them as total THQ (TTHQ) [36–38].

$$TTHQ \text{ (individual food)} = THQ \text{ (toxicant1)} + THQ \text{ (toxicant2)}$$
$$+ \dots\dots.. + THQ \text{ (toxicantn)} \tag{10}$$

To assess the overall non-carcinogenicity of two or more chemicals, a hazard index (HI) based on the USFPA guideline for health risk assessment of chemical mixtures is used [52]:

$$HI = \Sigma TTHQ = TTHQ(food-1) + TTHQ(food-2)$$
$$+ \dots\dots\dots\dots + TTHQ(food-n) \tag{11}$$

where RfD is an oral reference dose (mg/kg/day). An oral reference dose is a level of a substance that can be taken orally daily without causing adverse effects in the human population over a lifetime or lifetime oral exposure [38]. The RfDing (mg/kg/day) for Cr, Cd, and Pb was found to be 0.003, 0.001, and 0.0035, respectively [38]. EDI represents the average concentration of vegetables. The THQ is equal to or greater than 1, which indicates a potential health risk, and related intervention and protection measures should be taken [35]. It has been reported that exposure to two or more pollutants creates additive and/or interactive effects [46]. So, the values of TTHQ and HI are equal

to or greater than 1 for the exposed population, creating a potential health risk.

Carcinogenic Health Risk

The lifetime probability of cancer risk concomitant with the ingestion of vegetables by local residents or consumers due to exposure to lead, cadmium, and chromium is calculated as follows [35]:

The lifetime probability of cancer is asfollows :

$$\text{target carcinogenic risk, } TCR = EDI \times CSF_{ing} \tag{12}$$

$$\text{The sum of target carcinogenic risk, } Total\ TCR = \sum_{n=1}^{i} CR; i = 1, 2 \dots \dots, n \tag{13}$$

where EDI is the estimated daily intake of each heavy metal (mg/kg/day), CSF_{ing} is the ingestion cancer slope factor (mg/kg/day)$^{-1}$, and n is the number of heavy metals considered for cancer risk calculation. The slope factor is used in carcinogenic risk assessment to estimate the lifetime probability of an individual developing cancer as a result of exposure to a specific level of a potential carcinogen over time [35]. Here, CSF_{ing} for Cr, Cd, and Pb was documented as 0.5, 0.38, and 0.085, respectively [35, 46]. According to the USEPA, carcinogenic risks between 10^{-6} (1 in 1,000,000) and 10^{-4} (1 in 10,000) represent a range of permissible predicted lifetime risks for carcinogens, and the risk factor below 10^{-6} is eliminated from further consideration as a chemical of concern and the risk factor over 10^{-4} represents an unacceptable cancer risk [46, 48].

Statistical Analysis

Under the presumption that the continuous variable was normally distributed, a parametric test to compare the sample mean of the variable for two matched samples was examined. The assumption was upheld since the histogram was regularly distributed. SPSS 29.0 was used to compile the statistical analysis and some of the figures.

Results and Discussion

Heavy Metal Concentration in Soil Samples

In this study, the concentrations of three toxic heavy metals (Pb, Cd, and Cr) were determined for soil, fertilizer/pesticide, and vegetable samples using atomic absorption spectrometry in flame and graphite furnace modes, and the calculated data for soil samples were finalized as the mean concentration with standard deviation (Table 2).

According to the data from soil samples at both locations, Cr was the most abundant heavy metal detected in terms of quantity, followed by Pb and Cd. There was a notable difference in the Pb concentration in soil between locations A (6.20 ± 0.39 mg/kg) and B (21.39 ± 1.36). In soil samples collected at locations A and B, Cd levels ranged from 0.35 to 0.86 mg/kg and 0.28 to 0.80 mg/kg, respectively. In location B, a slightly higher amount of Cr (21.60 ± 2.56 mg/kg) was found than in location A (18.01 ± 2.24 mg/kg). Meanwhile, the soil background values for Pb, Cd, and Cr were reported as 20, 0.3, and 90 mg/kg, respectively [38]. Compared with these, the Cd content in the studied soil was significantly higher in some places (> 0.3 mg/kg) and indicated there might be the presence of a potential anthropogenic source of this metal. However, different studies were made in Bangladesh regarding heavy metal contamination in agricultural land in the industrial region and found in the range of 1.15–574, 0.07–16, and 0.08–1160 mg/kg for Pb, Cd, and Cr, respectively [38]. A recent study on agricultural land in a rural area (which can be considered a nonindustrial site) found heavy metal concentrations (Pb, Cd, and Cr) ranging from 9.10 to 23.66, 0.01–0.67, and 45.76 to 75.28 mg/kg, respectively [24]. The level of heavy metals in our study also followed the records. In our study, location B is surrounded by a lot of textile industries, tanneries, glass businesses,

Table 2 Mean concentration (mg/kg) with standard deviation (SD) of toxic heavy metals in soil samples for location A and location B

Soil sampling points	Mean concentration ± SD (mg/kg) at location A			Mean concentration ± SD (mg/kg) at location B		
	Pb	Cd	Cr	Pb	Cd	Cr
S-1	5.43 ± 0.35	0.86 ± .03	15.05 ± 1.79	19.84 ± 1.26	0.68 ± 0.02	18.16 ± 2.16
S-2	5.09 ± 0.32	0.68 ± .02	18.77 ± 2.23	21.12 ± 1.35	0.44 ± 0.02	21.46 ± 2.55
S-3	7.32 ± 0.47	0.45 ± .02	16.88 ± 2.00	22.5 ± 1.43	0.28 ± 0.01	21.08 ± 2.50
S-4	6.62 ± 0.42	0.36 ± .01	18.36 ± 2.18	21.41 ± 1.36	0.8 ± 0.03	22.02 ± 2.61
S-5	6.41 ± 0.41	0.35 ± .01	19.53 ± 2.32	22.86 ± 1.46	0.68 ± 0.02	23.12 ± 2.74
S-6	6.33 ± 0.40	0.63 ± .01	19.44 ± 2.31	20.6 ± 1.31	0.44 ± 0.02	23.74 ± 2.82
Range	5.09–7.32	0.35–0.86	15.05–19.53	19.84–22.86	0.28–0.8	18.16–23.74
Average	6.20 ± 0.39	0.56 ± 0.02	18.01 ± 2.14	21.39 ± 1.36	0.55 ± 0.02	21.60 ± 2.56

e-waste disposal sites, brick-making fields, high vehicular traffic, sewage effluent, etc., but location A is surrounded by a small amount of brick-making fields and coal mining sites in nearby districts. Those are polluting irrigation water, the main exposure pathway for soil [54]. A lot of studies have been done on the contamination of heavy metals in irrigation water. Therefore, the concentrations of heavy metals (Cr and Cd) in locations A and B were almost the same, indicating common sources of matter are involved in this metal content. But the higher level of Cd (> 0.3 mg/kg) in both locations indicated the influence of a common anthropogenic source; it might be an excessive use of fertilizer/pesticides or brick-making fields. Again, the potential level of Pb in location B indicated that industrial influences like e-waste and other metal processing industries might greatly affect this metal contamination. The paired sample *t*-test revealed that, on average, the Pb and Cr contents at location A were 15.19 and 3.59 points less, respectively, at 95% CI than at location B. The difference was statistically significant $p < 0.001$, two-tailed. The Cohen's d effect size for Pb was large (0.81) and for Cr was medium (0.57). This also indicated that location B was more affected than A in the case of Pb and Cr in soil samples.

Heavy Metal Concentration in Fertilizer/Pesticide Samples

A variety of chemical fertilizers or pesticides are frequently used in the cultivation of the collected vegetable samples. Toxic heavy metal concentrations in fertilizer/pesticide samples were measured using F-AAS (Pb and Cr) and GF-AAS (Cd) modes at the selected site, and the calculated data were finalized in mean concentrations with standard deviation (Table 3).

It was observed that toxic heavy metals were present in fertilizers/pesticides at both locations, which are frequently used in food production. In fertilizers/pesticides, Pb, Cd, and Cr concentrations were found at an average of 0.31 ± 0.02, 0.16 ± 0.006, and 1.96 ± 0.23 mg/kg for location A but 1.99 ± 0.13, 0.05 ± 0.002, and 2.8 ± 0.33 mg/kg for location B, respectively. There was a significant amount of toxic metals (Pb, Cd, and Cr) present in fertilizer/pesticide samples collected at locations A and B. Different countries like Australia, Canada, Japan, China, and the European Commission have fixed the standard permissible safety limit of Cd content in inorganic fertilizers as 50, 20, 8, 8, and 40 mg/kg, respectively, and Canada, Japan, China, and the European Commission have fixed Pb content in inorganic fertilizers as 500, 100, 100, and 150 mg/kg, respectively [17]. According to this, the levels of heavy metals in fertilizers/pesticides are clearly in a safe region. It also observed that studied fertilizers or pesticides might be responsible for heavy metal contamination in vegetables. And it was in compliance with the report published by New Age, a daily newspaper in Bangladesh [51]. A different study in Bangladesh recommended that inorganic fertilizers and pesticides might contain heavy metals [24]. But the pesticides are produced locally with imported, uncontrolled raw materials of low grade and no specific guidelines for production or use [24]. Thus, these metals could be exposed to pesticides and contaminate soil and vegetables. Consequently, we can consider that

Table 3 Mean concentration (mg/kg) with SD of heavy metals contained in fertilizer or pesticide samples for both locations

Fertilizer/pesticide sample code	Mean concentration ± SD (mg/kg) at location A			Mean concentration ± SD (mg/kg) at location B		
	Pb	Cd	Cr	Pb	Cd	Cr
FP-1	0.86 ± 0.05	1.18 ± 0.04	1.15 ± 0.14	1.98 ± 0.13	0.07 ± 0.003	1.31 ± 0.16
FP-2	< 0.2	0.63 ± 0.02	2.05 ± 0.24	2.27 ± 0.14	0.08 ± 0.003	1.03 ± 0.12
FP-3	< 0.2	< 0.001	4.58 ± 0.54	0.73 ± 0.05	0.08 ± 0.003	2.52 ± 0.30
FP-4	0.38 ± 0.02	< 0.001	7.6 ± 0.90	< 0.2	0.02 ± 0.001	0.78 ± 0.09
FP-5	< 0.2	< 0.001	2.29 ± 0.27	5.53 ± 0.35	0.04 ± 0.001	5.94 ± 0.71
FP-6	< 0.2	< 0.001	< 0.15	0.26 ± 0.02	0.03 ± 0.001	3.75 ± 0.45
FP-7	< 0.2	< 0.001	< 0.15	0.57 ± 0.04	$0.01 \pm .0001$	1.05 ± 0.12
FP-8	0.59 ± 0.04	< 0.001	< 0.15	0.87 ± 0.06	0.03 ± 0.001	1.15 ± 0.14
FP-9	< 0.2	< 0.001	1.1 ± 0.13	1.88 ± 0.12	0.02 ± 0.001	1.7 ± 0.20
FP-10	< 0.2	< 0.001	2.1 ± 0.25	2.59 ± 0.16	0.1 ± 0.004	1.57 ± 0.19
FP-11	< 0.2	0.02 ± 0.001	0.85 ± 0.10	3.83 ± 0.24	0.07 ± 0.003	6.59 ± 0.78
FP-12	1.08 ± 0.07	0.1 ± 0.004	1.52 ± 0.18	3.26 ± 0.21	0.09 ± 0.003	6.25 ± 0.74
Range	$< 0.2–1.08$	$< 0.001–1.18$	$< 0.15–7.6$	$< 0.2–5.53$	$0.01–0.1$	$0.78–6.59$
Average*	0.31 ± 0.02	0.16 ± 0.006	1.96 ± 0.23	1.99 ± 0.13	0.05 ± 0.002	2.8 ± 0.33

*Half of the detection limit was taken into account when determining the average value for items below the detection limit[53]

fertilizers and pesticides are potential sources of heavy metals used in vegetable production in Bangladesh.

Heavy Metal Concentration in Vegetable Samples

Finally, the concentrations of toxic heavy metals in vegetable samples from both locations were measured using GF-AAS (for Pb, Cd, and Cr), and the calculated data of the analyzed samples were finalized as mean concentrations with standard deviation (Table 4).

It was found that the Pb content in vegetable samples showed a significant quantity in both locations, where some values crossed the allowable limit prescribed by WHO. The Pb concentration in potatoes at location A showed the most abundance, whereas at location B, the cauliflower had the highest concentration. The green chili showed less abundance in both locations for the Pb level. The Cd level was almost equal in amount on average in both locations $(0.062 \pm 0.003$ mg/kg for location A and 0.060 ± 0.003 mg/kg for location B), with the highest amount in brinjal at location A $(0.084 \pm 0.004$ mg/kg) and flat been at location B $(0.168 \pm 0.002$ mg/kg). In terms of quantity, the Cd and Cr concentrations in the studied vegetables were clearly lower than the WHO's allowable limit. The Cr concentrations showed the highest in potatoes $(0.328 \pm 0.012$ and 0.365 ± 0.013 mg/kg) at both locations, with the lowest in brinjal $(0.102 \pm 0.004$ mg/kg) and green chili $(0.051 \pm 0.002$ mg/kg) at locations A and B, respectively. A recent study on vegetables near industrial areas, such as location B, discovered values for Pb, Cd, and Cr in the range of 0.78–18.04, 0.01–2.28, and 0.5–23.6 mg/kg, respectively [38, 54]. Again, some studies in rural areas discovered values in the 0.204–0.729, < 0.01--0.06, and < 0.01 mg/kg ranges for those metals, respectively [24]. It was aligned with the level of heavy metals in our study. It was revealed that a significant amount of Pb (> 0.3 mg/kg) was found in most of the vegetables, especially at location B. Again, the concentration of Pb in fertilizer/pesticides, and soils at location B was much higher than at location A. So, we cannot reject the influence of fertilizer/pesticides as a heavy metal source with industrial influences. The paired sample t-test revealed that on average, the Pb and Cr contents at location A were 0.24 and 0.044 points less, respectively, at 95% Cl than at location B. The difference (0.24) was statistically significant $p < 0.05$, two-tailed. The Cohen's d effect size for Pb was small (0.26), and for Cr and Cd, the difference was not statistically significant at the 95% CI. This indicated that location B was more affected than location A in the case of Pb exposure in vegetables.

Quality Indexes of Soil Samples and Source Identification

Quality Indexes

To follow the geochemically accumulated heavy metals into the soil, the geo-accumulation index (Igeo) of soil based on the heavy metal content followed the order Cd > Pb > Cr for both locations. Cadmium levels showed some positive value with moderately uncontaminated properties, but Pb and Cr levels showed that both locations were practically uncontaminated in all sampling sites (Fig. 2).

Since the Cd metal accumulation rate was high, the contamination of Cd in the soil was presumed to be higher than that of other metals that met the contamination factor (Cf) value. Based on the contamination level of the soil, Pb and Cr levels were shown as having low degrees of contamination, but Cd was moderately contaminated over a majority of the sites (Fig. 2). The enrichment factor (EF) is a useful method for determining the source of soil contamination from both human (anthropogenic) and natural sources. It was observed that the enrichment factor of heavy metals followed a sequence of Cd > Pb > Cr for all the sites at both locations. For all sampling sites

Table 4 Mean concentrations (mg/kg) with SD of heavy metals contained in vegetable samples at locations A and B

Vegetables (scientific name)	Mean concentration with SD at location A			Mean concentration with SD at location B		
	Pb	Cd	Cr	Pb	Cd	Cr
Potato (*Solanum tuberosum*)	*0.450 ± 0.016*	0.050 ± 0.002	0.328 ± 0.012	*0.505 ± 0.016*	0.053 ± 0.002	0.365 ± 0.013
Tomato (*Solanum lycopersicum*)	0.160 ± 0.006	0.053 ± 0.002	0.208 ± 0.008	0.235 ± 0.006	0.026 ± 0.002	0.295 ± 0.011
Flat green bean (*Phaseolus vulgaris*)	0.156 ± 0.006	0.055 ± 0.002	0.247 ± 0.009	*0.340 ± 0.006*	0.168 ± 0.002	0.320 ± 0.012
Brinjal (*Solanum melongena*)	0.205 ± 0.007	0.084 ± 0.004	0.102 ± 0.004	*0.485 ± 0.007*	0.029 ± 0.004	0.188 ± 0.007
Cauliflower (*Brassica oleracea*)	0.166 ± 0.006	0.059 ± 0.003	0.131 ± 0.005	*0.945 ± 0.006*	0.040 ± 0.003	0.290 ± 0.011
Green chili (*Capsicum annuum*)	0.111 ± 0.004	0.070 ± 0.003	0.190 ± 0.007	0.170 ± 0.004	0.043 ± 0.003	0.051 ± 0.002
Average	0.208 ± 0.007	0.062 ± 0.003	0.201 ± 0.007	*0.447 ± 0.007*	0.060 ± 0.003	0.311 ± 0.011
Range	0.111–0.450	0.050–0.084	0.131–0.328	0.170–0.945	0.026–0.168	0.051–0.365
*Allowable limit***	*0.3*	*0.2*	*2.3*	*0.3*	*0.2*	*2.3*

**Allowable limit according to WHO[46]

Fig. 2 Quality indexes of soil samples for location A and location B (levels were the same for both locations) with the risk level in terms of toxic metals
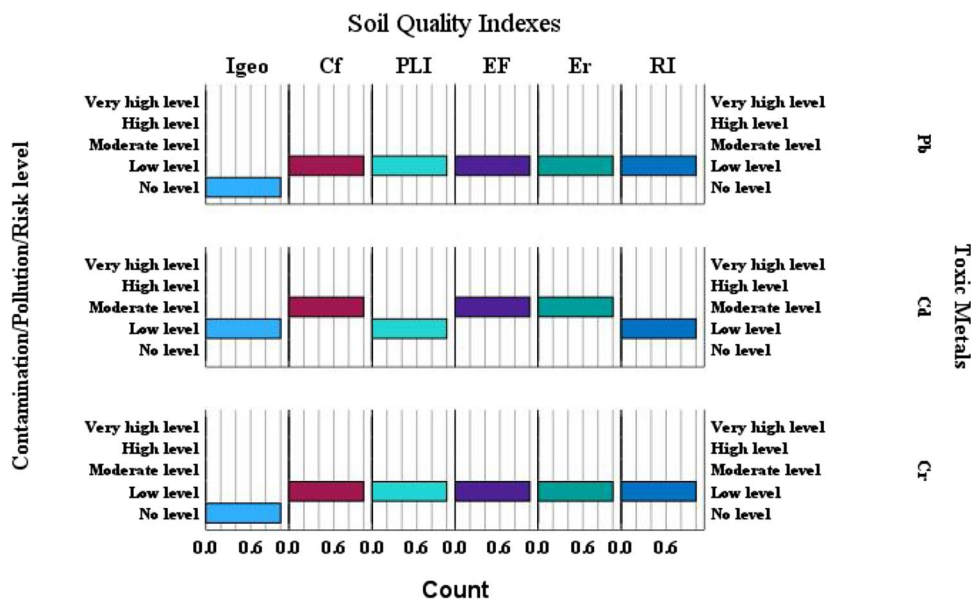
examined in the present study, enrichment factors regarding Pb and Cr ranged from 0.05 to 1.5, indicating that the metals detected in soil samples are from natural sources. In terms of EF of Cd, 67% and 83% of soil samples showed enrichment through human (anthropogenic) sources for locations A and B, respectively, with low to moderate impressions (Fig. 2). So, the soils of both locations were moderately affected by anthropological activities. The soil PLI of heavy metals is calculated to reveal and estimate any unwanted contamination. It was shown that the PLI value for soil samples at both locations was below 1, which denoted that vegetable-farmed soils at both locations contained a low degree of pollution (Fig. 2). Potential ecological risk for individual elements (Er) and potential ecological risk for overall elements (RI) have been assessed through the Hakanson method [42]. The study found that the Er value for soil samples revealed a decreasing order of Cd > Pb > Cr. The trend showed that Cd is likely to pose a significant ecological risk. Here, we saw that the data level of Er values for Pb and Cr was shown below 40, indicating a low potential ecological risk at both locations. In contrast, the Er values of Cd were within the range of 40–80, indicating moderate ecological risk for both locations (Fig. 2). The cumulative ecological risk index (RI) for both the sampling site and the location was assessed for ecological vulnerability to potentially toxic metals. The soil samples from location A and location B were found to be in low-risk regions (< 150) in the cumulative ecological potential risk assessment (Fig. 2). As a result, the toxic metal contamination of soil at specific sites did not pose a significant ecological risk. Overall, the soil quality indexes in the study area for toxic metals showed a low to moderate level of contamination and did not indicate any

significant ecological risk. The soil quality indexes in this study were comparable with other studies [55].

Heavy Metal Sources in Soil Samples

The study's findings showed that soil samples from locations A and B contained moderately enriched levels of Cd (0.56 mg/kg and 0.55 mg/kg, respectively), indicating anthropogenic sources of Cd (EF > 1.5). Different anthropogenic sources are present in both places, but brick-making fields, chemical fertilizers, and synthetic pesticides may be the most common sources of heavy metal (Cd) in the soil. According to this study, pesticides and fertilizers contain a moderate amount of heavy metals (Pb, Cd, and Cr). Numerous publications from Bangladesh and other nations have highlighted pesticides and phosphate fertilizers as heavy metal sources [17, 18, 21, 23–26]. Furthermore, the increased levels of Pb and Cr in location B (Pb-15.19 and Cr-3.59 points at 95% Cl) show that the hazardous metals (Pb and Cr) content in this area's soil has been contaminated by the moderate to high variation compared to location A. In principle, a small variation in heavy metal content was mainly caused by lithological variations in the formation of the soil [24]. But various glass and textile industries, as well as tannery businesses, are cantered near location B and may release harmful metals, including Cr and Pb [38, 54, 57]. However, in this case, the moderate to high variation between locations A and B indicated the industrial influence of toxic metals in the soil at location B. Therefore, to ensure safe and sustainable vegetable production, future studies should concentrate on limiting the sources of harmful metals.
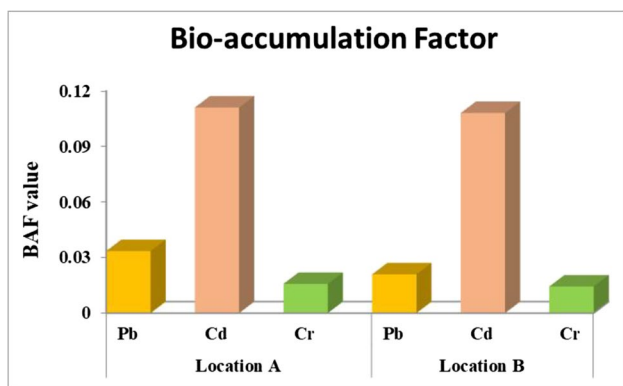
Fig. 3 Illustrates the average bioaccumulation factor of toxic metals at two different locations

Bioaccumulation Factor (BAF)

Numerous physical and chemical processes are involved in the entrance of dangerous metals into plants. The migration of harmful metals from the soil to plant tissue is referred to as bioaccumulation. The analytical report is depicted in Fig. 3, which shows the average bioaccumulation factor based on the average concentration of each heavy metal.

The BAF of heavy metals found in vegetables showed a decreasing order of Cd > Pb > Cr. Among the soil samples collected at both sites, Cd was the most bioavailable element, but Cr was the least. The higher the BAF of cadmium revealed, the greater the transfer of cadmium from soil to vegetables. The almost identical ionic radius and same ionic valence of Cd^{2+} and Ca^{2+} can be considered responsible for this, where Cd^{2+} can replace Ca^{2+} easily [54]. The translocation of Cd from soil to plant tissue followed the same channel for Cd and Ca. On the other hand, the reduction of Cr(VI) to Cr(III) might be attributed to the low bioavailability of Cr [54].

Human Health Risk Assessment Due to Ingestion of Vegetables

Estimated Daily Intake (EDI)

The EDIs of examined toxic metals for adult populations were determined methodically and revealed a decreasing trend of Pb > Cr > Cd in both locations. The consumption of Pb and Cr from potatoes was higher in both locations, as indicated in Table 5. Additionally, it was discovered that when the same type of vegetables was consumed, the EDI and total intake of the examined hazardous metals were greater for Pb and Cr at location B, but the Cd intake was higher at location A. It declared that 0.21, 0.07, and 0.2 mg/kg, respectively, were the maximum tolerable daily intakes (MTDI) for Pb, Cd, and Cr [46]. Therefore, the measured EDI value was much lower than the corresponding MTDI value. Nonetheless, the cumulative EDI values of the studied metals for the reference amount of vegetables consumed were lower than the MTDI values in both locations. Ahmed et al.'s [54] research in the industrial area discovered 56 times the EDI in comparison with the MTDI; however, Bushra et al.'s [24] investigation in rural regions discovered a considerably lower quantity than the MTDI. Again, the estimated daily intake refers to total exposure and consequence of heavy metals for inhabitants in a day at the study area. As a result, this study showed that the residents of the study regions do not experience any negative effects as a result of consuming the recommended quantity of vegetables.

Noncarcinogenic Health Risk

For the purpose of assessing the noncarcinogenic health risk associated with consuming the examined vegetables' three hazardous components, the target hazard quotient (THQ), total hazard quotient (TTHQ), and noncarcinogenic health hazard index (HI) were assessed. The results are shown in Table 6.

Table 5 The estimated daily intake (EDI) of toxic metals by an adult due to the consumption of vegetables at locations A and B

Vegetables	EDI values for location A			EDI values for location B		
	Pb	Cd	Cr	Pb	Cd	Cr
Potato	1.07E-04	1.18E-05	7.78E-05	1.20E-04	1.25E-05	8.65E-05
Tomato	3.78E-05	1.25E-05	4.93E-05	5.57E-05	6.13E-06	6.99E-05
Flat green bean	3.69E-05	1.30E-05	5.84E-05	8.06E-05	3.99E-05	7.58E-05
Brinjal	4.86E-05	1.99E-05	2.42E-05	1.15E-04	6.80E-06	4.44E-05
Cauliflower	3.92E-05	1.39E-05	3.11E-05	2.24E-04	9.50E-06	6.87E-05
Green chili	2.62E-05	1.66E-05	4.51E-05	4.03E-05	1.02E-05	2.37E-06
Average EDI	4.92E-05	1.46E-05	4.77E-05	1.06E-04	1.42E-05	5.80E-05
Total intake from vegetables	2.95E-04	8.77E-05	2.86E-04	6.35E-04	8.50E-05	3.48E-04
MTDI	*0.21*	*0.07*	*0.2*	*0.21*	*0.07*	*0.2*

Table 6 The THQ, total THQ, and HI for the consumption of vegetables at locations A and B

Vegetables	THQ for location A			THQ for location B			Location A	Location B
	Pb	Cd	Cr	Pb	Cd	Cr	TTHQ	TTHQ
Potato	0.030	0.012	0.026	0.034	0.013	0.029	0.068	0.076
Tomato	0.011	0.013	0.016	0.016	0.006	0.023	0.040	0.045
Flat green bean	0.011	0.013	0.019	0.023	0.040	0.025	0.043	0.088
Brinjal	0.014	0.020	0.008	0.033	0.007	0.015	0.042	0.054
Cauliflower	0.011	0.014	0.010	0.064	0.009	0.023	0.035	0.096
Green chili	0.007	0.017	0.015	0.012	0.010	0.001	0.039	0.022
Hazard index (HI)							***0.267***	***0.382***

The findings demonstrated that for both locations, all THQ values were significantly below the substantial risk value (<1) of noncarcinogenic health consequences related to vegetable intake. Once more, according to the TTHQ, the greatest values were shown by potatoes and cauliflower in areas A and B, respectively, while the lowest values were shown by cauliflower and green chili in the same regions. It mentioned that in their respective regions, the health effects of potatoes and cauliflower would be greater than those of other foods. In the examined location, the HI values for consumption of the recommended amount of vegetables likewise displayed lower values than the significant risk value (<1) [46]. At the same time, it mentioned that the noncarcinogenic risk pattern regarding TTHQ and HI for the present study showed higher levels for location B than location A, although it showed a totally safe region (<1) considering potential toxic elements. So, the noncarcinogenic risk evaluation through THQ, TTHQ, and HI for the adult population showed free of any possible health consequence for the metals examined. The outcome followed some recent studies in a different region of Bangladesh [24, 38, 54].

Carcinogenic Health Risk

The probable cancer risk (CR) is caused by ingestion of heavy metals on average for the lifetime duration based on individual metal exposures and cumulative exposure as presented in Table 7.

The findings revealed that the potential carcinogenic risks associated with consuming the tested vegetables in certain amounts exhibited a decreasing order of Cr > Cd > Pb, and every vegetable sample showed the possible risk levels below the threshold value (1.00E-04) [46]. Pb represented a very low value for both locations when the carcinogenic risk values were taken into account for each vegetable item, while Cd and Cr exhibited values between 1.00E-04 and 1.00E-06, suggesting an acceptable range for carcinogenic risk. Additionally, estimated cumulative components and the overall TCR for vegetable products also fell within the acceptable range. Here, total TCR for individual vegetable items followed the decreasing order of potato > flat green been > tomato > green chilli > cauliflower > brinjal in the case of location A, but for location B, it followed the order of flat green been > potato > cauliflower > tomato > brinjal > green chilli. This indicated that the potential carcinogenic risk from lifetime exposure to the studied metals is higher for potatoes in location A and flat green beans in location B. It stated that the potential health consequences for potatoes and flat green beans in their respective areas will be greater than for others because they are more bio-accessible for heavy metals in vegetables [54]. Overall, the probable carcinogenic health risk from consuming the prescribed total of vegetables for toxic metals will be within the acceptable range for individual vegetables and the cumulative approach, with location B indicating a little more concern for probable

Table 7 Target cancer risk (TCR) of heavy metals due to consumption of studied vegetables from locations A and B

Vegetables	Location A			Location B			Total TCR	
	Pb	Cd	Cr	Pb	Cd	Cr	Location A	Location B
Potato	9.07E-07	4.48E-06	3.89E-05	1.02E-06	4.76E-06	4.33E-05	4.43E-05	4.90E-05
Tomato	3.21E-07	4.75E-06	2.46E-05	4.73E-07	2.33E-06	3.50E-05	2.97E-05	3.78E-05
Flat green bean	3.13E-07	4.95E-06	2.92E-05	6.85E-07	1.51E-05	3.79E-05	3.45E-05	5.38E-05
Brinjal	4.13E-07	7.57E-06	1.21E-05	9.77E-07	2.58E-06	2.22E-05	2.01E-05	2.58E-05
Cauliflower	3.33E-07	5.27E-06	1.56E-05	1.90E-06	3.61E-06	3.44E-05	2.12E-05	3.99E-05
Green chili	2.23E-07	6.30E-06	2.25E-05	3.42E-07	3.87E-06	1.19E-06	2.91E-05	5.40E-06

cancer risk than location A. As a result, the potential carcinogenic risks for residents of the studied industrial areas (location B) from food ingestion should not be ignored.

Conclusions

The concentrations, pollution characteristics, and human health risks of three toxic heavy metals (Pb, Cd, and Cr) were determined in the soil-vegetable system of two discrete districts in Bangladesh. The concentration of Pb was much higher in vegetable farmland at location B than at location A, and fertilizer/pesticide used in vegetable production contained significant amounts of minerals. Among the elements, Pb showed significant contamination (>0.3 mg/kg) in vegetables at the study areas. Risk assessment models indicated that THQ were less than 1, indicating no probable significant noncarcinogenic health risks in the study areas. Among the vegetables, potatoes at location A and cauliflower at location B contributed to the highest noncarcinogenic ingestion risks. The evaluation of carcinogenic risks to adults in the study posed an acceptable range, meaning a low level of warning for the regions. Paired sample analysis showed that Pb and Cr were significantly higher in the soil at location B, and Pb in vegetables also contained significantly more at location B than at location A. Region B, which has been subjected to long-term industrial activities, must be evaluated for the potential effects of metal contamination on the health of the people who live there. The situation can be improved by continuous monitoring of heavy metals in industrial areas to follow the nature and movement of toxic metals.

Declarations

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