Translocation and bioaccumulation of trace metals from industrial effluent to locally grown vegetables and assessment of human health risk in Bangladesh

Md. Didarul Islam¹ · M. Mehedi Hasan² · Ashiqur Rahaman³ · Papia Haque¹ · Md. Sazedul Islam¹ · Mohammed Mizanur Rahman¹

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Abstract

In this study, we evaluated the level of trace metals in the soil of heavily loaded tannery and battery industry area on the bank of the Buriganga River, Dhaka, Bangladesh in order to investigate their translocation to the locally grown vegetables and potential health risk of the local consumers. Concentrations of various metals in agricultural soil and in a number of vegetables such as; Red amaranth (*Amaranthus cruentus*), Spinach (*Spinacia oleracea*), Jute leaf (*Corchorus capsularis*), Bottle Gourd (*Lagenaria siceraria*), Mustard green (*Brassica juncea*) and Water spinach (*Impomoea aquatica*) were determined by atomic absorption spectrometry. The content of chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) in the soil was around 500, 50, 50, 40, 0.8 and 200 mg/kg, respectively. Cr and Pb were found in the locally grown vegetables around 20 and 0.5 mg/kg respectively, which are higher than the permissible limit of them (2 mg/kg for Cr and 0.3 mg/kg for Pb) in vegetables as recommended by FAO/WHO and the data confirm the translocation of the metals from the soil to the vegetables. Hazard index value of all the vegetables considered was above 1, which indicates that the people could experience severe health risk due to consumption of any of those vegetables. Total cancer risk (TCR) value was obtained for Cr, Ni and Pb content in the local vegetables and it was observed that the value was around 1×10^{-3} for all of the sample vegetables. The high TCR values (higher than the USEPA threshold level of 1×10^{-6}) indicate that there is a potential cancer risk due to intake of vegetables grown in that area.

Keywords Trace metals · Potential health risk · Estimated daily intake · Hazard index · Hazard quotient · Total cancer risk

1 Introduction

Tannery industries are one of the oldest industries in Bangladesh. From the beginning to the present day, these industries are playing a crucial role in the economy of Bangladesh due to its large potential for employment, GDP growth and export. According to the Bangladesh Exports Promotion Bureau, in the fiscal year 2016–2017 (July–June), export earnings from the leather goods and footwear sector reached 1.23 billion US dollars [1]. In 1940,

tannery industries to produce leather products were first established in Naranayganj close to Dhaka, later on it was shifted to Hazaribagh area of Dhaka. These tanneries are directly associated with the pollution of Buriganga river by discharging untreated toxic effluents contaminated with heavy metals. They discharged $12,000 \text{ m}^3 \text{ day}^{-1}$ untreated effluents in the Buriganga River which contains at least 30% to 40% of unused Cr [2]. Battery manufacturing companies and metal smelting industries near the Buriganga River dump their metallic residue and unusable batteries

✉ Md. Sazedul Islam, sazid.acce@du.ac.bd | ¹Applied Chemistry and Chemical Engineering, University of Dhaka, Dhaka 1000, Bangladesh. ²Applied Chemistry and Chemical Engineering, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Goaplganj 8100, Bangladesh. ³Institute of Leather Engineering and Technology, University of Dhaka, Dhaka 1000, Bangladesh.

in the river. These metallic residues contain heavy metals like Pb, Cd, Zn, Ni etc. As a consequence of throwing and dumping of wastes and effluents containing various heavy metals in the river, not only river water but also the soil and vegetables of nearby area get polluted. Heavy metal pollution of soil and vegetables is one of the most severe ecological problems in the world as food chain contamination is the major pathway of heavy metal exposure for humans [3]. Metal uptake by food crops grown on such contaminated soils is high considering the high bio-availability of metal ions [4]. Metal transport from the river water to nearby agricultural land may be happened either by diffusion of metal ions from water to soil or by the overflow of the water to the bank of the river during rainy season. By overflow of the river water, cultivated lands are submerged and got toxic metal contamination [5]. Heavy metals in effluents penetrate into the soil during rainfall and are eventually accumulated into plants. After accumulation metals are translocated into various parts of the plants and through food chain manages to reach to human body [6]. Concentrations of the metals in different vegetables depend on soil composition, water, nutrient balance, as well as metal permissibility, selectivity and absorption ability of the vegetable species which varies from species to species [7]. Enrichment of trace metals in the vegetables is generally assessed by considering the metal levels in the soil in relation to the plant materials which is most commonly expressed as accumulation factor (AF) [8, 9]. Not all the metals taken by plants are considered harmful for human, some metals present in vegetables play important role biochemically and physiologically from health point of view [10]. Metals like Co, Cr(III), Cu, Fe, Mn, and Zn help in regulating human metabolism [11, 12]. However, excessive content of metals beyond Maximum Permissible Level leads to number of nervous, cardiovascular, renal, neurological impairment as well as bone diseases and several other health disorders. Moreover, the presence of Cd and Pb in a very low concentration can cause various metabolic disorders resulting extremely serious consequences [13].

Several methods have so far been proposed by several researchers to estimate the potential health risks of pollutants [14]. One of the best methods for evaluating potential non-carcinogenic health risks associated with long-term exposure to chemical pollutants in foodstuff is the hazard quotient (HQ) of the pollutants developed by USEPA (2005) [15, 16]. HQ is the ratio between the estimated daily intake (EDI) of any pollutant and the oral reference dose (R_fD) for it. According to Wang et al., if the HI (which is the total HQ) value of two or more pollutants is > 1 , the consumers are already experiencing adverse health effects to some extent. On the other hand, carcinogenic health risk due to several metals may be calculated by target cancer risk (TCR) value [17].

In this research, the amount of various metals both essential (Ni, Cu, and Zn) and non-essential (Cr, Pb, and Cd) present in locally cultivated six vegetables (Red amaranth (*Amaranthus cruentus*), Spinach (*Spanacia oleracea*), Jute leaf (*Corchorus capsularies*), Bottle Gourd (*Lagenaria siceraria*), Mustard green (*Brassica juncea*) and Water spinach (*Impomoea aquatic*) are determined. Health risk assessment for the consumers of those vegetables are estimated by using several types of parameter like EDI, HQ, HI and TCR. The main objective of this study is to estimate noncarcinogenic and carcinogenic health risks of the consumers of locally grown vegetables in the Hazaribagh area, Dhaka, Bangladesh.

2 Materials and methods

2.1 Sample collection

For analysis, the samples were collected from the agricultural land beside the Buriganga River located Washpur, Hazaribagh, Dhaka which is about 1.5 km away from Rayer Bazar where untreated tannery effluent was directly discharged. These agricultural lands get immersed under water during rainy season and usually remain water logged for around 3 months. After water dries up from the land, vegetables cultivation starts.

Soil of six different locations near the Buriganga River was taken in a distance of 10–100 m range and the sites are labeled as S1, S2, S3, S4, S5 and S6 (shown in the map shown in Fig. 1). To evaluate the uptake and accumulation of various metals in vegetables, six different types of vegetables were collected from each of the six locations. These vegetables were given an identification number (ID) for the ease of the study and presented in Table 1 along with their local name and scientific name.

2.2 Digestion of the soil samples

Soil samples were digested for atomic absorption spectroscopic analysis (AAS) as described by McGrath et al. [18]. In brief, soil samples were grinded and passed through a 1 mm sieve to remove stones, roots and plant residues and then dried at 105°C for 8 h to remove moisture completely. 3 g of soil sample was weighted and taken into a glass test tube and then 8 ml of conc. HCl (37% Merck, Germany) and 2 ml of conc. HNO_3 (69%, Merck, Germany) was added. This mixture was then allowed to digest overnight at room temperature. Then reflux was done for 2 h at 120 °C for complete digestion. After cooling, total volume of the content was made 50 ml with deionized water. Then solution was filtered through Whatman no. 42 filter paper.

Fig. 1 **A** World Map; **B** Map of Bangladesh with its capital Dhaka; **C** Map of capital Dhaka with marked central Dhaka; **D** Map of sampling area in Hazaribagh tannery which is situated 4.87 km from the University of Dhaka

Table 1 Local name, scientific name and ID of the sample vegetables grown in the vicinity of Hazaribagh industrial area

Local name	Scientific Name	Vegetable ID
Red amaranth	<i>Amaranthus cruentus</i>	RA
Mustard green	<i>Brassica juncea</i>	MG
Jute	<i>Corchorus capsularis</i>	Ju
Water spinach	<i>Impomoea aquatica</i>	WS
Bottle gourd	<i>Lagenaria siceraria</i>	BG
Spinach	<i>Spanacia oleracea</i>	Sp

Each sample was digested in replicates of five and stored in polyethylene plastic bottles at 4 °C till analysis [19, 20].

2.3 Digestion of the vegetable samples

Vegetable parts were digested in CEM® microwave digester (MARS Xpress, USA; Model-907511) according to the manufacturer guideline. In brief, samples were cleaned with vinyl brush and cut into small pieces. The edible parts and roots of each vegetable samples were washed separately with distilled and deionized water to remove dirt and then samples were dried in a hot air oven at 70–80 °C for 24 h. The samples were then allowed to cool to room temperature in a desiccator, before further use. The size of the samples was again reduced below 0.4 mm by grinding to facilitate complete digestion.

About 0.5 g of each of the samples was transferred into a Teflon vessel and kept the vessel open for a minimum of 15 min for pre-digestion purpose. The vessels were then sealed and the samples were digested with 12 ml of concentrated HNO₃ acid (69%, Merck, Germany) and 4 ml of H₂O₂ (30%, Merck, Germany) at 200 °C in microwave digestion system. The Microwave digestion of the samples was conducted with a 1600 W power supply, temperature ranging from 180 to 220 °C, and holding time of 15 min. After digestion, total volume of the content was made 50 ml with deionized water. The digested samples were then filtered by using 0.45 µm syringe filter (each samples were digested and analyzed for five times for the estimation of reproducibility test) and solutions were stored in 50 ml polypropylene tubes at 4 °C till analysis [21].

2.4 AAS analysis of the samples

Concentration of the metals in the samples was measured by using a Perkin-Elmer flame atomic absorption spectrometer (Model-AAAnalyst 800, USA) equipped with a deuterium lamp for background correction. For atomization, an air/acetylene flow at a fixed ratio was constantly maintained and concentrations of metals were measured by using specific hollow cathode lamp (HCL) at a fixed wavelength. Blank samples of deionized water were accompanied after and before every run of analysis and five replicate samples were estimated. The wavelengths used for the determination of the metals

were 228.8, 357.9, 324.8, 232.0, 283.3, and 213.9 nm for Cd, Cr, Cu, Ni, Pb, and Zn, respectively [20]. Results were summarized and represented in mg/kg unit. Lower detection limit of flame AAS for Cd, Cr, Cu, Ni, Pb, and Zn metals were 0.8, 3.0, 1.5, 6.0, 15.0 and 1.5 µg/l respectively [22].

2.5 Data analysis

2.5.1 Uptake, translocation, and accumulation of metals by the plants

Biological concentration factor (BCF) was calculated from metal concentration ratio of plant roots to soil [23] according to Eq. 1. Translocation factor (TF) was evaluated from the ratio of heavy metals in plant's edible part to that in plant root as shown in Eq. 2 [24]. Biological accumulation factor (BAF) was calculated from the ratio of heavy metal in shoots to that in soil according to Eq. 3 [25]:

$$BCF = \frac{C_{\text{root}}}{C_{\text{soil}}} \quad (1)$$

$$TF = \frac{C_{\text{edible part}}}{C_{\text{root}}} \quad (2)$$

$$BAF = \frac{C_{\text{edible part}}}{C_{\text{soil}}} \quad (3)$$

where $C_{\text{edible part}}$, C_{root} and C_{soil} represent the heavy metal concentration in extracts of edible part and roots of the vegetable and soil samples on dry weight basis, respectively.

2.5.2 Estimated daily intake (EDI) of metals

The EDI of trace metals depends on metal concentrations (for dry weight basis), daily consumption rate and the average body weight of consumers. EDI for each metal can be determined by following formula [26].

$$EDI = \frac{C_m \times IR \times EF \times ED}{BW \times AT} \quad (4)$$

where C_m = concentration of a metal in mg/kg; IR (ingestion rate) = 0.167 kg/day; EF (exposure frequency) = 365 day/year; ED (exposure duration) = 70 year; BW (body weight) = 60 kg; AT (average time for non-carcinogens) = 365 × 70 day.

2.5.3 Health risk assessment

In this study, the non-carcinogenic health risks associated with the consumption of the locally produced vegetables

were assessed based on HQ of any metal and calculations were made using the following equation [27]. The unit of R_fD is $\text{mg kg}^{-1} \text{ day}^{-1}$.

$$HQ = \frac{EDI}{R_fD} \quad (5)$$

HI from HQs is expressed as the sum of the HQ of all the metals, which was determined by the following equation [28].

$$HI = \sum_{k=1}^n HQ_k \quad (6)$$

where HI is the sum of more than one HQ for multiple substance or multiple pathways. If HI value is < 1, that means there is not carcinogenic risk of consuming the vegetables on a regular basis and if HI value comes > 1, that means there is a carcinogenic risk after intake of the metals in the measured quantity from the consumption of the vegetables.

The possibility of cancer risks through the intake of heavy metals due to consumption of the vegetables can be estimated by using the following equation

$$CR = EDI \times CPS \quad (7)$$

where CR represents the probability of individual lifetime health risks from carcinogens, unit of EDI is the $\text{mg kg}^{-1} \text{ day}^{-1}$; CPS is the oral carcinogenic slope factor (mg/kg day^{-1}). Since CPS values were not available for all selected trace metals, so the CR of Cr, Ni, and Pb, were calculated only to indicate the lifetime carcinogenic risk to the consumers. CPS value of Cr, Ni and Pb are 5×10^{-1} , 1.7 and 8.5×10^{-3} respectively [29].

The cumulative cancer risk was calculated by the following equation. The acceptable range of TCR is within the range of (10^{-6} – 10^{-4}), which means within this value there is no probability of carcinogenic attack after intake of specified metals [30].

$$\text{Total cancer risk (TCR)} = \sum_{k=1}^n CR_k \quad (8)$$

3 Results and discussion

3.1 Trace metals concentration in soil

The concentration of each metal in different soil samples has been summarized along with the Dutch standard of soil in Table 2. The concentrations of metals in the present study were compared with the Dutch soil quality guidelines as no guideline values were established for trace

metals in the soil of Bangladesh. Cr and Pb were found to be present in higher quantity in the soil samples as compared to their standard values. Cr and Pb concentrations were observed almost five and two times higher than their standard values, respectively. There were more than 200 tannery industries near the agricultural field, which use chrome salts for tanning. In tanning process, excess chrome salts are usually used for complete crosslinking of collagen in the skin of animals. The untreated effluent of this process and trimmed wastes of Cr tanned leather result in rising of Cr content in the soil after being thrown in the nearby environment. Battery manufacturing and Pb smelting industries in this area dump non-usable and rejected battery wastes in nearby locality and these wastes probably release Pb in the environment slowly. Concentrations of Ni and Cu were slightly higher and Zn content was slightly lower in the sample soils than their standard values as specified in the Dutch soil standard, which may be due to the establishment of many metal processing industries in that area. The variation of different heavy metals in different sample locations may be due to the capability of mobility of these metal ions.

3.2 Trace metals concentration in the local vegetables produce

Phytostabilization, rhizofiltration, phytoaccumulation, and phytovolatilization are the mechanisms responsible for uptake, translocation and accumulation of metal ions in any plant [4, 21]. Metal ions uptake by a plant depends on various factors such as chelating agents produced in plant roots, pH change induced by plants and redox reaction [31]. The estimated value of metal ions concentration in root and edible parts of various plants has been illustrated in Fig. 2. Total concentration of metal ions present in RA, MG, Ju, WS, BG and Sp were calculated 68.44, 78.90, 66.65, 69.33, 68.32 and 54.60 mg/kg, respectively. Total metal concentration was found highest in case of MG and the lowest for Sp. It may be due to the fact that MG belongs to Brassica family and act as hyper-accumulator [32]. The concentration of different heavy metal varies from plant to

plant, due to their different accumulation abilities, properties of medium, environmental condition, bioavailability of the metal, root zone and various soil properties [28, 31].

The total amount of essential plant micronutrients (summation of the concentration of Cu, Ni, and Zn) are found higher in RA (12 mg/kg), BG (1 mg/kg) and Ju (26 mg/kg) than in other plants. Among the non-essential metals, Pb was found the highest in BG and lowest in Sp; Cd was found highest in Sp and lowest in WS; and Cr was found highest in WS and lowest in Sp.

Cr was found to be accumulated the highest in concentration in all plants than any other metals ranging from 54 mg/kg for WS to 25 mg/kg for Sp which is definitely due to the highest bioavailability of Cr in soil compared to other metals [31, 33]. Among all metals, only Pb and Cr content in vegetables crossed the safety limit set by FAO/WHO and Chinese Ministry of Health (CMH) [34, 35]. Pb content in soils was found in high quantities with an average of 197 mg/Kg, which catalyzed the high bioaccumulation of Pb due to rapid uptake capacity from soil to plant's root and root to edible parts. This is probably because plants can solubilize and take up Pb from its partially insoluble form from the soil [31].

From the data of the various metal ion concentrations in different parts of the vegetables, BCF, TF and BAF of the sample vegetables were calculated according to Eqs. 1, 2, and 3, respectively and their values have been presented in Table 3.

The highest BCF was found for Cu in RA. The total BCF was also found higher in RA compared to any other plants, which indicates that RA has higher tendency towards metal precipitation on root than others which might be due to its massive fibrous root system [36]. BCF of non-essential metals (Cr, Cd and Pb) were observed higher in Sp, MG, and RA compared to those of other vegetables.

A key trait of metal hyperaccumulators is the efficient metal transport from roots to edible parts, characterized by the TF being > 1 [37]. Plant's essential metals like Cu, Ni and Zn showed TF > 1 for most of the plant species. For Cu, TF was > 1 in RA, MG and Sp while for Ni, TF was > 1 in MG, WS, BG and for Zn TF was > 1 in RA, Ju, WS, BG. The

Table 2 Concentration of trace metals in soil samples (mg/kg)

Sample ID	Cr	Ni	Cu	Zn	Cd	Pb
S1	491	36.60	37.21	26.71	0.56	131.89
S2	455	57.41	54.21	52.42	0.91	169.12
S3	561	55.97	46.32	38.38	0.85	299.55
S4	501	48.07	44.53	36.24	0.82	210.96
S5	525	57.92	50.93	35.14	0.47	194.81
S6	537	65.46	57.45	44.25	0.92	177.20
Mean concentration	512 $\pm$ 37	54 $\pm$ 10	48 $\pm$ 7	39 $\pm$ 9	0.8 $\pm$ 0.2	197 $\pm$ 57
Dutch standard	100	35	36	140	0.8	85

Fig. 2 Estimated concentrations of different metals in various parts of the vegetables collected from the sampling area

Table 3 BCF, TF and BAF values of different metals in the sample vegetables

Plants	Parameter	Cr	Ni	Cu	Zn	Cd	Pb
RA	BCF	0.04	0.02	0.15	0.08	0.02	0.03
	TF	0.43	0.39	1.11	1.32	1.00	0.77
	BAF	0.02	0.01	0.17	0.11	0.02	0.02
MG	BCF	0.07	0.01	0.03	0.08	0.01	0.01
	TF	0.63	1.49	1.82	0.73	1.00	1.71
	BAF	0.04	0.01	0.05	0.05	0.01	0.01
Ju	BCF	0.04	0.00	0.05	0.04	0.04	0.02
	TF	0.42	0.80	0.62	1.11	0.70	1.31
	BAF	0.02	0.00	0.03	0.05	0.03	0.02
WS	BCF	0.06	0.00	0.03	0.01	0.02	0.01
	TF	0.69	1.81	0.00	1.22	0.92	1.30
	BAF	0.04	0.00	0.00	0.05	0.01	0.02
BG	BCF	0.04	0.01	0.03	0.05	0.03	0.02
	TF	0.63	2.21	1.00	1.45	0.92	1.66
	BAF	0.03	0.01	0.03	0.08	0.02	0.03
Sp	BCF	0.04	0.00	0.04	0.10	0.09	0.01
	TF	0.34	1.00	1.04	0.37	0.82	1.13
	BAF	0.01	0.00	0.04	0.04	0.07	0.01

higher uptake of essential metals in vegetables may be due to higher transpiration rate to maintain the growth and moisture content of these plants. In literature, TF value for only WS (0.30–5.40) and Sp (0.17–0.89) are available, of them TF value of all metals are found below 1 except Cu in WS (5.40).

Among plant's non-essential metal ions, Cr showed the lowest affinity to translocate from root to edible parts. It might be due to the phytostabilization of the plants which renders the translocation of metal ions and demobilize them in the roots [38]. Cd showed TF of equal or < 1 in all cases. It affirmed that Cd was not translocated to the edible parts as great as Pb which may be due to its low concentration in roots.

In this study, Pb showed $TF < 1$ only for RA. RA belongs to Amaranthaceae family, so it has comparatively high lead in its root than other parts due to massive fibrous root system which provides large surface area to accumulate lead in the root and it also prevent translocation of Pb in the edible parts. TF value for Pb for other plants is found > 1 suggesting the effective translocation of Pb from the roots to the shoots [39].

BAF represents the tendency of the plant to accumulate metal in the consuming part of it. Depending on this value plants can be hyperaccumulator ($BAF > 1$) or excluder ($BAF < 1$). In this study, BAF was found < 1 for all metals in all plants which suggested that these plants only absorbed heavy metals but did not accumulate them (excluders). BG showed the highest BAF values for Ni and Pb while RA showed the highest BAF for Cu and Zn. BAF of Cr and Cd were found greater in WS and Sp. When compared with other studies as shown in Table 4, a lower BAF value is observed which can be attributed to difference in location, soil properties (concentration of metals in soil, pH, organic matter, clay content, cation exchange capacity, metals forms or speciation in soils), vegetable tissue uptake efficiency and growth factors.

Various factors may influence heavy metal solubility and as a consequence the availability for plants [46]. Cr in the soil present in various oxidation states, among them Cr(VI) is highly soluble and more toxic. BCF for total Cr in each of the plants studied is < 1 , that means that Cr uptake from the soil is not very high though in Table 2. It was observed that the concentration of Cr is the highest among all the metals tested in all soil samples in this study. TF for Cr was obtained the lowest (0.4–0.6) among all the metals studied. According to Valerie. et al. [47], Cr can retain in the roots due to insolubilization (e.g., at the root surface and in the root apoplast) or to a compartmentation in cells avoiding the release to the xylem. The BAF value for Cr was also obtained quite low (0.02–0.04).

TF values obtained for Ni (0.39–2.2), Zn (0.7–1.4) were little higher than for Cd (0.7–1). The symplastic transport

via the phloem allows a redistribution of nutrients, assimilates and pollutants within the plants. Ni and Zn are highly phloem-mobile and can be redistributed in crop plants throughout vegetative growth and the reproductive phase [47]. Cd is less phloem-mobile than Zn, but it is also to some extent redistributed via the phloem [47]. BAF values for Ni (0–0.01), Zn (0.05–0.1) and Cd (0.01–0.07) are observed quite low, this may be due to the redistribution of the metals from senescing leaves via the phloem to growing vegetative parts and maturing fruits.

TF value (0–1.8) and BAF value (0–0.17) obtained for Cu were like those for Ni, Zn and Cd. It is reported that Cu form metal complex with nicotianamine and was proposed to be important for the translocation of Cu from leaves to developing organs and maturing seeds [48, 49]. It is also reported that metallothioneins such as cysteine-rich proteins in plants have high affinity for binding metal cations such as Cd, Cu and Zn [50].

BCF values obtained for Pb is in the range of (0.01–0.03) which means a small portion of Pb from the soil is probably taken up by the plants. However, the TF value (0.7–1.6) is high that represents the translocation of Pb from root to shoot/leaves of the plants studied. Though the TF value and BAF value (0.01–0.03) obtained for Pb were close to the those values determined in this study for other metals except Cr, the mechanism of Pb uptake and translocation within plants is different from others'. Dan et al. [51] suggested that lignifications of cell wall and formation of metal-lignin complex might be one of the primary mechanisms of Pb tolerance in the roots of scented Geranium plant. Sekara et al. studied Pb contamination of nine crops and found the highest deposition of lead in leaves than in its' roots of all plants other than barley and maize [52].

3.3 Health risk assessment

3.3.1 Hazard quotient estimation

Health risks of the residents in the study area, through consumption of these vegetables, were evaluated by HQ obtained by estimating EDI using Eqs. 4 and 5. Table 5 represents the EDI values of the metals studied and their R_fD values. The R_fD values were obtained from Integrated Risk Information Systems [53]. EDI values of Pb was obtained above or very close to the R_fD value in case of all plants except Spinach. However, it was noticed that EDI values of most of the metals were obtained below the R_fD values.

HQ values of each metal were calculated according to Eq. 4 and their value has been summarized in Table 6. HQ values of most of the metals were found < 1 except that of Pb in case of RA, Ju, and BG. HI values were derived from HQ. HI values of RA, Ju, BG, Sp, MG, and WS were obtained

Table 4 Comparison of the obtained BCF and TF values in this study with that obtained for the studied metals and plants in other studies

Sample ID	Element	TF and BAF values obtained in this study		TF and BAF values found in literature		Reference
		TF	BAF	TF	BAF	
RA	Cr	0.43	0.02	–	0.02	[40]
	Ni	0.39	0.01	–	–	
	Cu	1.11	0.17	–	0.09	
	Zn	1.32	0.11	–	0.57	
	Cd	1.00	0.02	–	1.16	
	Pb	0.77	0.02	–	0.06	
MG	Cr	0.63	0.04	–	0.794	[41]
	Ni	1.49	0.01	–	11.668	
	Cu	1.82	0.05	–	0.208	
	Zn	0.73	0.05	–	0.195	
	Cd	1.00	0.01	–	0.435	
	Pb	1.71	0.01	–	0.436	
Ju	Cr	0.42	0.02	–	0.83	[42]
	Ni	0.80	BDL	–	0.24	
	Cu	0.62	0.03	–	1.45	
	Zn	1.11	0.05	–	2.68	
	Cd	0.70	0.01	–	–	
	Pb	1.31	0.02	–	0.45	
WS	Cr	0.69	0.04	–	–	[43]
	Ni	1.81	BDL	0.60	1.80	
	Cu	BDL	BDL	5.40	BDL	
	Zn	1.22	0.05	0.30	11.90	
	Cd	0.92	0.01	0.50	1.00	
	Pb	1.30	0.02	–	–	
BG	Cr	0.63	0.03	–	2.00	[44]
	Ni	2.21	0.01	–	3.50	
	Cu	1.00	0.03	–	0.29	
	Zn	1.45	0.08	–	0.67	
	Cd	0.92	0.02	–	1.41	
	Pb	1.66	0.03	–	11.48	
Sp	Cr	0.34	0.01	0.40	0.03	[45]
	Ni	1.00	0.00	0.45	0.06	
	Cu	1.04	0.04	0.51	0.35	
	Zn	0.37	0.04	0.89	0.43	
	Cd	0.82	0.07	0.65	0.27	
	Pb	1.13	0.01	0.17	BDL	

BDL below detection limit

2.53, 2.18, 2.11, 2.1, 1.75 and 1.36, respectively. According to Lemly [54], HI = (1–10) refers to moderate hazard. In an independent study in a mining area of China [55] and in a Cu and Ni mine and smelter area in Botswana of Africa [25], HI were found 2.1 and 2.89, respectively. The results of HI values in this study obtained in the range of (1.36–2.53), which was noticed to be as hazardous as mentioned in the above mining area. HI found in this current study suggested that a significant effect will be found for longtime exposure in near future.

3.4 Cancer risk assessment

International Agency for Research on Cancer (IARC) classified Ni, Cr, and Pb as predominant contaminants to be potential carcinogenic element [57]. The exposure of the people in the studied area to Cr, Ni and Pb contamination after daily consumption of the locally grown vegetables may be health hazardous to them. This is why, the probability of an individual for lifetime health risks from carcinogens (CR) and total cancer risk (TCR) were calculated

according to Eqs. 7 and 8, respectively and the results were summarized in Table 7.

The CR values of Cr and Ni were found to be lower than the hazardous limit whereas that of the Pb was found higher in RA, Ju and BG than the reference limit. TCR was calculated from the CR values and it was found the highest of 3387×10^{-4} for BG and the lowest of 811×10^{-4} for Sp. The calculated risk values indicated that the consumption of bottle gourd, mustard green, red spinach, water spinach, jute leaves and spinach would result in an excess of 3387, 2380, 2329, 1225, 1067 and 811 cancer cases per 10,000 people, respectively. USEPA considers excess cancer risks that are below about 1 chance in 1,000,000 (1×10^{-6}) to be so small as to be negligible, and risks above 1 in 10,000 (1×10^{-4}) to be sufficiently large that some sort of remediation is desirable

[58]. TCR > 1 in ten thousand ($TCR > 10^{-4}$) is benchmark for gathering additional information whereas one in one thousand ($TCR > 10^{-3}$) is moderately increased risk and should be given high priority as a public health concern [59]. In this study, all the plants have resulted in a value of $TCR > 10^{-3}$, which would cause moderately increased risk of cancer. Chronic exposure to low doses of Ni and Pb could, therefore, may result in many types of cancers [60]. Though the risk assessment of Cr estimated from the sampling data was observed less than the specified value of USEPA, it is worthy to be mentioned that the toxicity of chromium depends on its chemical form. Cr (VI) compounds having a toxic, mutagenic and even carcinogenic nature, however, Cr(III) which prevails in food-stuffs has no associated toxicity [61].

Table 5 R_fD values and estimated EDI values of different heavy metals through consumption of the sample vegetables

Species	Elements						Total EDI
	Cr	Ni	Cu	Zn	Cd	Pb	
	EDI (mg kg ⁻¹ day ⁻¹)						
RfD [13, 29, 56] (mg kg ⁻¹ day ⁻¹)	1.50	0.02	0.040	0.30	0.0005	0.003	
RA	0.09	0.0023	0.036	0.08	0.0001	0.004	0.21
MG	0.15	0.0021	0.011	0.07	0.0001	0.003	0.24
Ju	0.11	0.0007	0.011	0.08	0.0002	0.004	0.2
WS	0.16	0.0007	0.004	0.04	0.0001	0.003	0.21
BG	0.11	0.0034	0.009	0.08	0.0001	0.004	0.21
Sp	0.08	0.0006	0.014	0.07	0.0004	0.002	0.16

Table 6 Calculated HQ and HI values of different heavy metals through consumption of the vegetable's samples

Species	Elements						HI
	Cr	Ni	Cu	Zn	Cd	Pb	
	HQ						
RA	0.06	0.11	0.890	0.26	0.14	1.060	2.53
MG	0.10	0.11	0.290	0.22	0.16	0.880	1.75
Ju	0.07	0.04	0.280	0.26	0.38	1.150	2.18
WS	0.11	0.04	0.100	0.12	0.14	0.850	1.36
BG	0.07	0.17	0.220	0.26	0.14	1.250	2.11
Sp	0.05	0.03	0.350	0.24	0.85	0.580	2.1

Table 7 CR and TCR values of the consumer of the locally produced vegetables from the study area in Bangladesh

Element	CPS (mg/kg. day^{-1})	CR values ($\times 10^{-4}$)					
		RA	MG	Ju	WS	BG	Sp
Cr	5×10^{-1}	288	515	350	543	371	251
Ni	1.7	1951	1790	620	609	2910	510
Pb	8.5×10^{-3}	90.3	75	97.6	72.1	106	49.5
TCR		2329	2380	1067	1225	3387	811

4 Conclusion

Metal contamination in soil is gaining increasing attention all over the world. Principally, there are two major pathways for human exposure to soil contamination, one is soil–plant–human (food chain pathway) and another one is soil–human (incidental soil ingestion). The present study focused on food chain pathway. From the present investigation, it is clear that the agricultural land near Hazaribagh is already contaminated by heavy metals. Chromium and lead content exceed the FAO/WHO recommended permissible limits in vegetables. HQ for individual metal was below 1 in most of the cases, suggesting that people would not experience significant health hazards if they ingest a single metal from vegetables, but cumulative effect as shown by HI value was found > 1 for all the vegetables tested. It indicates that people would experience noncarcinogenic health risks due to consumption of them. The carcinogenic risks of Cr, Ni, and Pb through consumption of the vegetables were obtained higher than the USEPA threshold level (1×10^{-6}), indicating potential cancer risks. This suggests that more attention should be given particularly to Cr, Ni, and Pb levels in the soil to assure food safety to local consumers and to protect them from serious lifetime health risks.

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Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

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