Environmental Science
ISSN: 0974-7451

Environmental Science: An Indian Journal

Research | Vol 13 Iss 5

Heavy Metals in Common Edible Vegetables of Industrial Area in Kushtia, Bangladesh: A Health Risk Study

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Received: August 26, 2017; **Accepted:** September 18, 2017; **Published:** September 20, 2017

Abstract

This study investigated heavy metals concentration in vegetables collected from the suburban area of Kushtia district in Bangladesh as well as their detrimental effects on public health *via* dietary intake. Concentration of five heavy metals (As, Mn, Zn, Cd and Pb) in the eight vegetables were measured using AAS. Heavy metals concentration for experimented vegetables were found to be higher than the safe limits suggested by FAO/WHO, except As for brinjal, Zn for green papaya and cauliflower, and Pb for tomato, bean and spinach. The values of the estimated daily intake (EDI), target hazard quotients (THQ), hazard index (HI), and carcinogenic risks (CRs) were measured to evaluate the carcinogenic and non-carcinogenic health risks. The values of EDI for tested metals were found below the maximum tolerable daily intake (MTDI). In addition, the individual values of THQs and their total (*T*THQ) with exception of As, were greater than unity, that indicated the potential non-carcinogenic health risk to the consumers. Furthermore, HI>1 which may possess potential health risks. However, calculated values of the total CRs (TCRs) of As (7.40E-03) and Pb (1.05E-04) were higher than the USEPA standards. These results of tested vegetables picked out the possible lifelong carcinogenic and non-carcinogenic health risks to consumers due to intake of under the current consumption rate.

Keywords:* *Common edible vegetables; Heavy metals contamination; Estimated daily intake (EDI); Health risk assessment

Introduction

Heavy or dense metals are of great concern as they are non biodegradeable and persistent for a lifetime in the human body through dietary intake or other exposure sources [1-3]. Interacting this pipeline, vegetables are the important food of daily diet because they are the good source of Vitamin A and C, iron, calcium, folic acid and fiber [4]. These food products are easily contaminated with heavy metals due to natural activities (weathering and volcanic eruptions), and anthropogenic activities (rapid industrialisation, vehicular exhaust, wastewater irrigation, sludge applications in agricultural area etc.) [5-7]. A few heavy metals such as Cd, Pb, As have been identified as the most toxic elements in the atmosphere as well as in soil

Citation: Islam R, Kumar S, Karmoker J, et al. Heavy Metals in Common Edible Vegetables of Industrial Area in Kushtia, Bangladesh: A Health Risk Study. Environ Sci Ind J. 2017;13(5):150

and water. In the list of priority pollutants of US Environment Protection Agency (USEPA), heavy metals such as Cd, Pb and As have been placed [8-9]. Environment Protection Agency has placed Cd and Pb in group B2 indicated Cd and Pb being possible human carcinogens [10]. IARC has classified Cd compounds as carcinogenic to human (Group 1) and inorganic Pb compounds (Group 2A) as probably carcinogenic to human. Similarly, Pb has been classified as possibly carcinogenic to human (Group 2B) and As has been placed in group A by USEPA [11]. Hence, it is undoubtedly noticed that the contamination of vegetables by heavy metals should be determined with great priority based on the assessment of health risks. In contrast, it is obvious that the degree of accumulation of heavy metals depends on the soil type, plant species, growth condition of the plant, presence of other ions in the soil [12].

A regular monitoring survey has been performed in various part of the world to measure the heavy metals concentration in the edible parts of the vegetables [13-15,4,6]. In order to determine the extent of environmental contamination by heavy metals, the degree of human exposure and potential health risks via vegetable consumption, a several number of studies has been carried out in Bangladesh [16-17]. However, in Kushtia district, no studies have been done to evaluate the non-carcinogenic and carcinogenic health risk of heavy metals through vegetable consumption.

The area of Kushtia district in Bangladesh is suffering from great pollution with congestion, rapid expansion in urban area for rapid industrialization and a number of anthropogenic activities. Therefore, the objective of this study was to evaluate the contamination status and health risk of toxic heavy metals such as As, Pb, Cd, Mn, and Zn in eight different edible vegetable species at Kushtia industrial area of Bangladesh.

Materials and Methods

Study area

The common edible vegetables: Carrot (*Daucus carota*), potato (*Solanum tuberosum*), brinjal (*Solanum melongena*), tomato (*Lycopersicon lycopersicum*), bean (*Lablab purpureus*), green papaya (*Carica papaya*), cauliflower (*Brassica oleraceae var botrytis*) and spinach (*Spinacea oleracea*) were collected in April 2015 from the industrial area of Kushtia district, the western part of Bangladesh under Khulna division (FIG. 1).

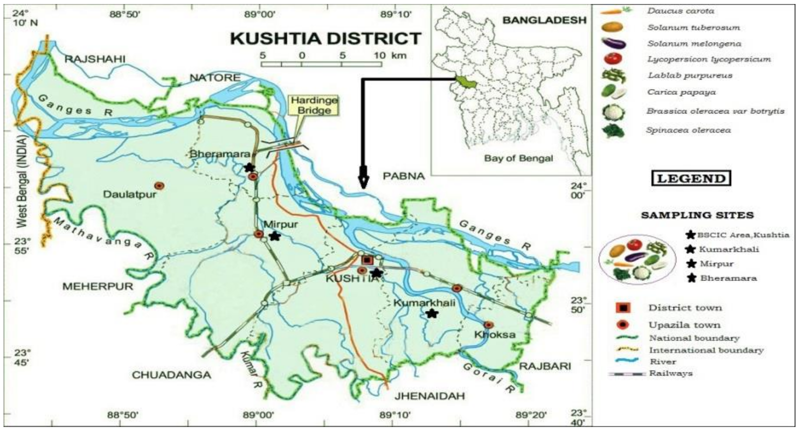

FIG. 1. **Maps where samples were collected in Kushtia district of Bangladesh.**

It is located at 23.90 latitudes and 89.12 longitudes and is situated at elevation 17 m above sea level, with an area of 1608.80 square kilometers. The district is bordered by Rajshahi, Natore, Pabna districts to the north, by Chuadanga and Jhenaidah districts to the south, by Rajbari district to the east, Meherpur district to the west, and an international boundary to the West Bengal of India to the west. The main rivers: Ganges (Padma), Gorai, Mathabhanga, Kaliganga and Kumar are flowing through the district. The temperature ranges between 37.8°C to 9.2°C and an annual rainfall average is 1,467 millimeters.

Sampling and pretreatment of samples

The vegetable samples were randomly collected from agricultural fields near the industrial area of Kushtia district each of three times in a year. Only the consumable parts of the sample were selected and washed primarily with tap water, and then deionized water so as to remove any soil and dirt particles. Then the samples were partially dried in air and cut down into small pieces with a knife of stainless steel. The small pieces of samples separately were dried in an electric oven at 80°C for 48 h time period to get a constant dry weight. Then dried samples each of three were taken into a mortar and pestle made of ceramic to grind them. The powdered samples were passed through 2 mm mesh of nylon wire, and then kept in zipped polyethylene bag at room temperature for digestion.

Digestion of the previously treated samples

The powdered samples (each of 1 g) were treated with a mixture of three acids such as nitric acid (HNO_3), sulfuric acid (H_2SO_4) and perchloric acid ($HClO_4$) in the volume ratio of 5:1:1 and controlled temperature at 80°C for three hours up to the samples solution became transparent. After cooling at room temperature, the samples were filtered with Whatman cellulose filter papers and diluted to 50 ml with deionized water [18].

Heavy metals analysis by AAS

Atomic absorption spectrophotometer (AAS Varian SpectrAA-220) fitted with a specific hollow cathode lamp of particular metal and direct flame (air-acetylene) was used to determine the heavy metals (As, Mn, Zn, Cd and Pb). The wavelengths were 279.5 nm for Mn, 283.3 nm for Pb, 228.8 nm for Cd, and 213.9 nm for Zn. Arsenic was analyzed with hydride vapor generation (HVG) method using argon as a carrier gas at wavelength 193.7 nm [19]. Blanks and calibration with standard solutions were also analysed by the same method. The results were expressed as mg/Kg body weight/day.

Quality control

Analysis of the samples and measurement of quality control were followed by the steps. Analytical grade chemical reagents were used, various metal stock solutions were prepared from high purity compound (99.9%) purchased from Sigma-Aldrich (St. Louis, MO, USA). Freshly prepared double deionized distilled water used to avoid contamination which was produced by three steps procedure as, distillation, deionization, and ultra-purification.

Data analysis

Estimated daily intake (EDI) of heavy metals: The estimated daily intakes (EDI) of heavy metals due to ingestion of vegetables were estimated using the following equation:

$$EDI = (FIR \times CM) \div BW \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

CM: Concentration of heavy metal in vegetable samples (mg Kg^{-1} fresh weight);

FIR: Vegetables ingestion rate (0.17004 Kg $person^{-1}$ day^{-1}) [16];

BW: Average body weight (60 Kg $person^{-1}$) taken from the ''Report of the household income and expenditure survey 2010'' [16,20].

Non-carcinogenic risks assessment: To estimate non-carcinogenic risks, the target hazard quotient (THQ) and total target hazard quotient (TTHQ) were calculated as per Environmental Protection Agency (USEPA) Region III's risk-based concentration table by using the following equation [21]:

$$THQ = \quad EFr \times ED \times FIR \times CM \; \div \; RfDo \times BW \times AT \quad \times 10^{-3} \text{............ } 2$$

$$TTHQ(individual\ vegetable) = THQmetal\ (1) + THQmetal\ (2) + THQmetal\ (3) + \ldots\ldots + THQmetal\ (n) \ldots\ldots\ldots\ldots (3)$$

In order to assess the overall potential for non-carcinogenic health effects from more than one heavy metal, a hazard index (HI) formulated based on the guidelines for health risk assessment of chemical mixtures as follows [11]:

$$HI = TTHQ\ vegetable(1) + TTHQ\ vegetable\ (2) + TTHQ\ vegetable\ (3) + \ldots\ldots + TTHQ\ vegetable\ (n) \ldots\ldots\ldots\ldots\ldots (4)$$

Where,

TTHQ: Total THQ from individual vegetable item;

THQ: Target hazard quotient (dimensionless);

EFr: Exposure frequency (365 days $Year^{-1}$);

ED: Exposure duration (70 years);

CM: Concentration of heavy metal in vegetable (mg Kg^{-1} fresh weight);

FIR: Vegetables ingestion rate (170.04 Kg $Person^{-1}$ day^{-1}) [16];

BW: Average body weight (60 Kg $Person^{-1}$) drawing from the ''Report of the household income and expenditure survey 2010'';

AT: Average exposure time for noncarcinogenic effects (ED × 365 days $Year^{-1}$);

R_fDo: Oral reference dose (mg Kg^{-1} day^{-1}).

The RfDos were 0.0003, 0.14, 0.3, 0.003 and 0.0035 mg Kg^{-1} day^{-1} for AS, Mn, Zn, Cd, and Pb respectively [22]. It is presumed that all arsenic ions are inorganic to determine the appropriate R_fDo for THQ. When the value of THQ is less than unity, the exposed population is unlikely to experience certain harmful effects. If THQ is greater than unity there is a potential non-carcinogenic health risk and suitable remedies and defensive measurements are required to be taken.

Carcinogenic risks of As and Pb: Carcinogenic risk (CR) is the possibility of an individual lifetime health risk from carcinogens by selected heavy metals. The carcinogenic risk (CR) factor (lifetime cancer risk) of As and Pb can be calculated as [11]:

$$CR = \{(EFr \times ED \times FIR \times CM \times SF) \div (RfDo \times BW \times AT)\} \times 10^{-3} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where,

AT: Average exposure time for noncarcinogenic effects (ED × 365 days $Year^{-1}$);

SF: Oral slope factor ($mgKg^{-1}$ $Day^{-1})^{-1}$;

Oral slope factor from the Integrated Risk Information System USEPA database was 1.5 and 8.5×10^{-3} $(mg/kg/d)^{-1}$ for As and Pb [22].

The total carcinogenic risk (TCR) of individual heavy metal of all vegetables can be calculated from the following equation:

$$TCR = CRvegetable\ (1) + CRvegetable\ (2) + CRvegetable\ (3) + \ldots\ldots + CRvegetable\ (n) \ldots\ldots\ldots\ldots (6)$$

Statistical analysis

Data were statistically analysed using Statistical Package for the Social Sciences (SPSS) version 20. One-way analysis of variance (ANOVA) was performed to determine the significant differences of metal concentrations among eight vegetables. The significance was set at 95% confidence level.

Results and Discussion

Heavy metals concentrations in vegetables

Mean concentrations and standard deviations of five heavy metals: As, Cd, Pb, Mn and Zn in eight different vegetables from Kushtia district in Bangladesh are listed in TABLE 1. Considerable variations in the concentration of As, Cd, Pb, Mn and Zn were observed from the same sampling location. This may be due to the variations in their morphology and physiology for heavy metal ingestion, accumulation, ejection, and retention [4]. It was observed that the ranking order of mean concentrations of the heavy metals in the vegetables were As<Cd<Pb<Mn<Zn. The arsenic (As), cadmium (Cd), lead (Pb), manganese (Mn) and zinc (Zn) in the vegetable samples were in the range of 0.10 to 0.43, 0.13 to 0.55, 0.33 to 0.80, 2.01 to 6.49 and 16.83 to 49.89 mg/Kg-body weight/day respectively.

TABLE 1. **Overview the concentration of heavy metals in the vegetables collected from agricultural fields in Kushtia industrial area of Bangladesh.**

Vegetables	Scientific name	Heavy metals (mg/Kg body wt./day)^a				
		As	Mn	Zn	Cd	Pb
Carrot	*Daucus carota*	0.18 ± 0.01^a	2.12 ± 0.31^e	39.58 ± 3.01^c	0.36 ± 0.05^a	0.80 ± 0.09^a
Potato	*Solanum tuberosum*	0.14 ± 0.01^a	2.01 ± 0.30^e	42.98 ± 3.33^b	0.55 ± 0.07^a	0.61 ± 0.06^a
Brinjal	*Solanum melongena*	0.10 ± 0.00^a	3.92 ± 0.43^{cd}	26.03 ± 2.78^f	0.48 ± 0.05^a	0.57 ± 0.05^a

Tomato	*Lycopersicon lycopersicum*	0.13 ± 0.02^{a}	4.61 ± 0.52^{bc}	49.89 ± 4.37^{a}	0.27 ± 0.03^{a}	0.42 ± 0.03^{a}
Bean	*Lablab purpureus*	0.23 ± 0.02^{a}	2.71 ± 0.39^{e}	26.66 ± 2.79^{f}	0.24 ± 0.03^{a}	0.48 ± 0.05^{a}
Green papaya	*Carica papaya*	0.37 ± 0.03^{a}	3.99 ± 0.42^{cd}	17.39 ± 1.57^{h}	0.13 ± 0.01^{a}	0.56 ± 0.04^{a}
Cauliflower	*Brassica oleracea var botrytis*	0.16 ± 0.01^{a}	3.47 ± 0.37^{d}	16.83 ± 1.46^{h}	0.34 ± 0.05^{a}	0.59 ± 0.04^{a}
Spinach	*Spinacea oleracea*	0.43 ± 0.04^{a}	6.49 ± 0.61^{a}	33.92 ± 3.11^{d}	0.42 ± 0.04^{a}	0.33 ± 0.03^{a}
*Mean ± SD for all vegetables		0.22 ± 0.02^{a}	3.67 ± 0.42^{d}	31.66 ± 2.80^{e}	0.35 ± 0.04^{a}	0.54 ± 0.05^{a}
**FAO/WHO, 2011		0.10	-	20	0.05	0.50

^{a} Values within the same column with different letters are significantly different ($P<0.05$)
†BDL: Below Detection Limit of AAS; As (BDL: 0.0005 mg/L); Mn (BDL: 0.009 mg/L)
Zn (BDL: 0.005 mg/L); Cd (BDL: 0.002 mg/L); Pb (BDL: 0.002 mg/L)
*(Mean ± SD) (mg Kg^{-1} fresh weight)
**Permissible limit in mg Kg^{-1} fresh weight

Arsenic (As): Arsenic is widespread in the environment because of both natural and anthropogenic processes. It is a ubiquitous, but potentially toxic trace element. Generally Arsenic and its compounds come in soil through ground water, by-product of metal smelting, burning fossil fuels, agricultural chemicals, and glass materials, pharmaceuticals, and metallic alloys. Since our tested vegetables were collected from Kushtia industrial area, Arsenic (As) may contaminate through ground water, soil eroded water by Padma river *via* Ganga-Kapotakkho (GK) water route for irrigation project or by industrial effluents which may pose a potential threat [23,24]. According to FAO/WHO [25], arsenic concentration in vegetables should not exceed 0.10 mg/Kg. The highest concentration of As was found at 0.43 mg/Kg in spinach whereas the lowest at 0.10 mg/Kg in brinjal. In the present study, arsenic concentrations in the selected vegetables were slightly higher than the permissible limit of FAO/WHO [25] except brinjal (TABLE 1). Statistically, all the samples did not show significance difference ($P>0.05$). Previous studies reported that concentration of As was 0.07 to 3.9 mg/Kg in vegetable of Jamalpur and Chandpur districts [26] and 0.04 to 1.9 mg/Kg in vegetables of Comilla, Rajshahi and Sathkhira districts in Bangladesh [27]. Arsenic concentration of vegetables was found at 0.009 to 7.9 mg/Kg in Patuakhali [16] and 0.01 to 0.2 mg/Kg in Noakhali [28]. The concentration of As in vegetables collected from different areas of Bangladesh ranged from 0.005 to 0.5 mg/Kg [12].

Manganese (Mn): Manganese is a low toxicity element which has considerable biological significance. No maximum is identified for manganese in vegetables. Statistically, there was a significance ($P<0.05$) different in Mn concentration among all selected vegetables. Spinach exhibited the maximum Mn concentration of 6.49 mg/Kg and potato showed the minimum of 2.01 mg/Kg. Normally, vegetables contain Mn concentration ranging from 6.93 to 28.35 mg/Kg [29,30]. In the current study, Mn concentration determined in all the selected vegetables were below the literature values.

Zinc (Zn): Zinc is a major essential element required in human physiological system. It is highly harmful to humans when its concentration level exceeds tolerable limits. According to FAO/WHO, the maximum permitted concentration for Zn was 20 mg/Kg body weight/day. A research reported that chronic exposure to Zn and/or Cu is associated with Parkinson's disease [30]. Vegetables are known to possess a high threshold level of Zn. There were significant ($P<0.05$) differences in Zn concentration among all the studied vegetables. The highest amount of Zn was observed in tomato (49.89 mg/Kg) and the lowest was in cauliflower (16.83 mg/Kg) among the eight-vegetable species (TABLE 1). From the literature survey, Zn concentration in different vegetables of Bangladesh ranged from 5.0 to 5.3 mg/Kg [31], 1.9 to 4.8 mg/Kg [32], and 19.54 to 42.06 mg/Kg [33]. In our study, among all the eight vegetable samples, only cauliflower and green papaya were below the permissible level of Zn recommended by FAO/WHO (TABLE 1).

Cadmium (Cd): Cadmium is an element capable of producing chronic toxicity present at minimum concentration of 1 mg/Kg [17]. According to FAO/WHO, Cd concentration in vegetables should not exceed 0.05 mg/Kg. In this study, the highest amount of Cd was observed in potato (0.55 mg/Kg) and the lowest amount in papaya (0.13 mg/Kg). Statistically, all selected vegetables did not show significance difference ($P>0.05$). A research [34] found the concentration of Cd (0.01 to 0.22 mg/Kg) in Jessore district of Bangladesh. In previous studies, the concentration of Cd in different vegetables was found at 0.03 mg/Kg [35], 0.1 mg/Kg [16], 0.06 mg/Kg [28]. In the present study, the concentration of Cd for all selected vegetables was significantly ($P<0.05$) higher than the literature. This may be due to the long-term discharge of untreated industrial wastes, fertilizers which could pollute the vegetables.

Lead (Pb): Lead is a well-known and non-essential element that can cause nephrotoxicity, neurotoxicity, and many others adverse health effects [28]. Lead contents in gasoline by car exhausts mixed with soil near roads, metal smelting, battery manufacturing, painting on the outside of buildings and other factories that use lead. This lead gets into the air and then mixes with the soil. The agricultural soils in Kushtia District, Bangladesh contain higher amount of lead (Pb) which may cause the lead availability in vegetables [36,37]. From the literature, the concentration of Pb ranges from 0.005 to 0.057 mg/Kg [29], 0.03 to 6.3 mg/Kg [12] and 0.7 to 17 mg/Kg [28]. In accordance with FAO/WHO, Pb concentration in vegetables should not exceed 0.50 mg/Kg as fresh weight basis. Statistically, there was not significance ($P>0.05$) different in Pb concentration among all selected vegetables. The highest concentration of Pb was found in carrot (0.80 mg/Kg) and the lowest was in spinach (0.33 mg/Kg). The present study showed that the Pb concentration of all selected vegetables was higher than the maximum allowable limit of FAO/WHO (TABLE 1) except tomato, bean, and spinach [23].

Estimated daily intake (EDI) of heavy metals

Heavy metals transport from plants to human through oral, dermal, and nasal [38]. As a basis for estimating a population diet in terms of daily intake levels of nutrients, bio-active compounds and contaminants, the dietary exposure of vegetables is used. This provides vital information for the potential nutritional deficiencies or exposure to food contaminants [39]. The EDI of heavy metals were calculated according to the average concentration of each heavy metal in each vegetable species, and the corresponding consumption rate [40]. TABLE 2 showed the overview of EDI for five heavy metals in vegetables. The mean values of total EDI of heavy metals in the selected vegetables were found 4.97E-03 mg/Kg for As, 8.32E-02 mg/Kg for Mn, 7.19E-01 mg/Kg for Zn, 7.91E-03 mg/Kg for Cd and 1.24E-02 mg/Kg for Pb. These were lower than the maximum tolerable daily intake (MTDI). The raking order of EDI values was observed Zn>Mn>Pb>As>Cd (TABLE 2).

TABLE 2. **Estimated daily intake (EDI) of heavy metals from consumption of the vegetable species collected from Kushtia district of Bangladesh.**

Vegetables	**EDI of heavy metals (mg/Kg body wt./day)**[a]				
	As	**Mn**	**Zn**	**Cd**	**Pb**
Carrot	5.11E-04 ± 2.84E-04	6.02E-03 ± 8.80E-04	1.12E-01 ± 8.55E-03	1.02E-03 ± 1.42E-05	2.27E-03 ± 2.56E-04
Potato	3.98E-04 ± 2.84E-05	5.71E-03 ± 8.52E-04	1.22E-01 ± 9.46E-03	1.56E-03 ± 1.99E-04	1.73E-03 ± 1.70E-04
Brinjal	2.84E-04 ± 0.00	1.11E-02 ± 1.22E-03	7.39E-02 ± 7.90E-03	1.36E-03 ± 1.42E-04	1.62E-03 ± 1.42E-04
Tomato	3.69E-04 ± 5.68E-05	1.31E-02 ± 1.48E-03	1.42E-01 ± 1.24E-02	7.67E-04 ± 8.52E-05	1.19E-03 ± 8.52E-05
Bean	6.53E-04 ± 5.68E-05	7.70E-03 ± 1.11E-03	7.57E-02 ± 7.92E-03	6.82E-04 ± 8.52E-03	1.36E-03 ± 1.42E-04
Green papaya	1.05E-03 ± 8.52E-05	1.13E-02 ± 1.19E-03	4.94E-02 ± 4.46E-03	3.69E-04 ± 2.84E-05	1.59E-03 ± 1.14E-04
Cauliflower	4.54E-04 ± 2.84E-05	9.85E-03 ± 1.05E-03	4.78E-02 ± 4.15E-03	9.66E-04 ± 1.42E-04	1.68E-03 ± 1.14E-04
Spinach	1.22E-03 ± 1.14E-04	1.84E-02 ± 1.73E-03	9.63E-02 ± 8.83E-03	1.19E-03 ± 1.14E-04	9.37E-04 ± 8.52E-05
EDI of vegetables	4.97E-03	8.32E-02	7.19E-01	7.91E-03	1.24E-02
[b]MTDI	1.30E-01	2.00E00 to 5.00E	6.00E+01	2.10E-02	2.10E-01

[a]Each value in the table represnts the mean ± SD of three measurements
[b]MTDI, maximum tolerable daily intake [29]

Non-carcinogenic health risks assessment

The target hazard quotient (THQ) is used to determine the non-carcinogenic health risk levels due to pollutant exposure. When the value of THQ is higher than unity, there is a probability of non-carcinogenic health risks [41]. THQ values of five tested heavy metals in the selected vegetables are shown in TABLE 3. The values of THQ for all the heavy metals with exception of Mn were higher than unity, indicating the uptake of a single metal through vegetable consumption may cause significant potential health risks. The increasing order of total THQ (*T*THQ) of vegetables were found brinjal<tomato<cauliflower<potato<bean<carrot<papaya<spinach. The summation of *T*THQ of individual heavy metal termed as hazard index (HI). When the value of HI exceeded unity, it may pose health hazards [42].

In the present study, the value of HI (25.58) was higher than unity. FIG. 2 showed the percentage of THQ of heavy metals for the selected vegetable ingestion. The highest percentage of THQ in the selected vegetables was As (61.21%), followed by Pb (12.55%), Cd (12.25%), Zn (11.06%) and Mn (2.93%).

T

ABLE 3. **Overview of non-carcinogenic risks (THQ and TTHQ) of heavy metals from consumption of the vegetable species collected from Kushtia district of Bangladesh.**

Vegetables	**THQ values of heavy metals***					**†*T*THQ**
	As	**Mn**	**Zn**	**Cd**	**Pb**	
Carrot	1.70E-00 ± 9.45E-02	4.29E-02 ± 6.28E-03	3.74E-01 ± 2.84E-02	3.40E-01 ± 4.72E-02	6.48E-01 ± 7.29E-02	3.10
Potato	1.32E-00 ± 9.45E-02	4.07E-02 ± 6.07E-03	4.06E-01 ± 3.15E-02	5.20E-01 ± 6.61E-02	4.94E-01 ± 4.86E-02	2.78
Brinjal	9.45E-01 ± 0.00	7.94E-02 ± 8.70E-03	2.46E-01 ± 2.63E-02	4.53E-01 ± 4.72E-02	4.62E-01 ± 4.05E-02	2.19
Tomato	1.23E-00 ± 1.89E-01	9.33E-02 ± 1.05E-02	4.71E-01 ± 4.13E-02	2.55E-01 ± 2.83E-02	3.40E-01 ± 2.43E-02	2.39
Bean	2.17E-00 ± 1.89E-01	5.49E-02 ± 7.89E-03	2.52E-01 ± 2.64E-02	2.27E-01 ± 2.83E-02	3.89E-01 ± 4.05E-02	3.09
Green papaya	3.50E-00 ± 2.83E-01	8.08E-02 ± 8.50E-03	1.64E-01 ± 1.48E-02	1.23E-01 ± 9.45E-03	4.53E-01 ± 3.24E-02	4.32
Cauliflower	1.51E-00 ± 9.45E-02	7.02E-02 ± 7.49E-03	1.56E-01 ± 1.38E-02	3.12E-01 ± 4.72E-02	4.78E-01 ± 3.24E-02	2.53
Spinach	4.06E-00 ± 3.78E-01	1.31E-01 ± 1.23E-02	3.20E-01 ± 2.94E-02	3.97E-01 ± 3.78E-02	2.67E-01 ± 2.43E-02	5.18
T*THQ*	16.44	0.59	2.39	2.63	3.53	††**HI**=25.58

*Each value in the table represnts the mean ± SD of three measurements.
**Total THQ of individual metal
†Total THQ of individual vegetable
††Sum of *T*THQ: Hazard Index (HI); if *T*THQ or HI<1 means Non-carcinogenic risks

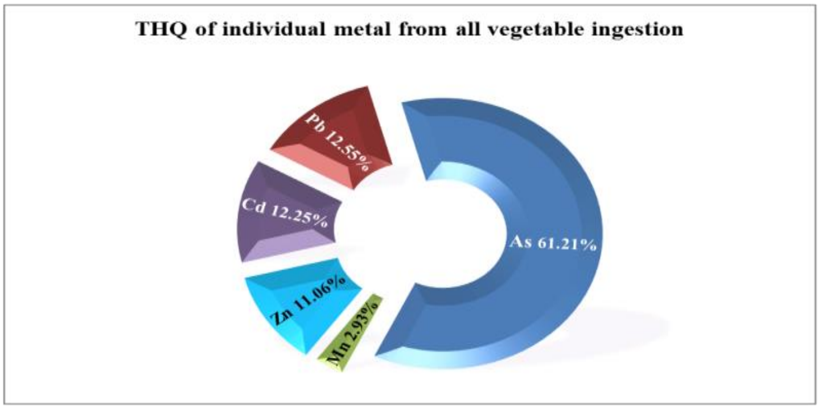

FIG. 2. **Target hazard quotient (THQ) of individual metal from selected vegetables.**

Carcinogenic health risks assessment

Heavy metal concentrations especially As and Pb in Environment without anthropogenic influences are usually low and do not pose risks to humans or ecosystems. It would be more detrimental when it crosses its tolerable limits. In recent decades, anthropogenic activities like-agricultural, industrial, and mining have contributed to significant increases in the amount of these contaminants in the environment [43,44].

The carcinogenic risk (CRs) evaluated from the uptake of As and Pb in selected vegetables were calculated as these two metals may create both non-carcinogenic and carcinogenic health risks depending on the exposure dose. CRs values of As and Pb in the selected vegetables are shown in TABLE 4. CRs values of As ranged from 4.25E-04 in brinjal to 1.83E-03 in spinach. However, CRs values of Pb ranged from 7.95E-06 in spinach to 1.93E-05 in carrot. The values of CRs exceeded the acceptable limit 10^{-6} [21] indicating lifetime cancer risk to the subjected population consuming both metals through the vegetables. On the other hand, the TCRs values are lower than 10^{-6} which is considered to be negligible. Value more than 10^{-4} is considered as unacceptable [11], and values between 10^{-6} and 10^{-4} are generally considered as acceptable range [45]. In this study, the values of total carcinogenic risks (TCRs) of As and Pb were found as 7.40E-03 and 1.05E-04 respectively (TABLE 4). Therefore, based on the results of the present study, the potential health risk to the targeted population due to metal exposure *via* vegetables consumption should not be ignored.

TABLE 4. **Overview of carcinogenic risks (CRs) of As and Pb tested vegetables.**

Vegetables	**CRs values of heavy metals**[a]	
	As	**Pb**
Carrot	7.65E-04 ± 4.25E-05	1.93E-05 ± 2.17E-06
Potato	5.95E-04 ± 4.25E-05	1.47E-05 ± 1.45E-06
Brinjal	4.25E-04 ± 0.00	1.37E-05 ± 1.21E-06
Tomato	5.53E-04 ± 8.50E-05	1.04E-05 ± 7.23E-07
Bean	9.78E-04 ± 8.50E-05	1.16E-05 ± 1.21E-06
Green papaya	1.57E-03 ± 1.28E-04	1.35E-05 ± 9.64E-07
Cauliflower	6.80E-04 ± 4.25E-05	1.42E-05 ± 9.64E-07
Spinach	1.83E-03 ± 1.70E-04	7.95E-06 ± 7.23E-07
TCRs[b]	7.40E-03	1.05E-04

[a]Each value in the table represnts the mean ± SD of three measurements
[b]Total Carcinogenic risk (Mean values)
CRs acceptable limit is 10^{-6} and TCRs acceptable limit is 10^{-4} [21]

Conclusion

The present study illustrated that vegetables of Kushtia industrial area of Bangladesh accumulated As, Mn, Zn, Cd and Pb at high concentrations compared to maximum permissible limits. Five heavy metals were found to be considered as potential health hazards for consumers. The EDI values of tested metals in the selected vegetables were found below the MTDI level. The values of THQ and HI showed that the consumers have a warrant of non-carcinogenic health risk due to the vegetables contaminated with heavy metals. The high values of CRs as well as TCRs indicated that the consumers of these vegetables consisting of As and Pb might have lifelong carcinogenic health risks. Therefore, consumption of the vegetables in this area may create health risk in the long run. In this context, based on potential risks to ecosystems and human health, anthropic activities for the contamination of heavy metals should be reduced significantly that's would be the best way of remediation.

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