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Heavy Metals in Widely Consumed Vegetables Grown in Industrial Areas of Bangladesh: a Potential Human Health Hazard

Farzana Akter Laboni[1] · Md. Wadud Ahmed[2] · Abdul Kaium[1] · Md. Khairul Alam[3] · Aney Parven[1,4] · Md. Fahad Jubayer[5] · Md. Aminur Rahman[4] · Islam Md Meftaul[1,4] · Md. Sirajul Islam Khan[1]

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Abstract

The prevalence of heavy metals in frequently consumed vegetables constitutes a considerable public health hazard. This study aims to determine the quantity of heavy metals in widely consumed watercress (WC), alligator weed (AW), red amaranth (RA), spinach (SP), cauliflower (CF), and eggplant (EP) cultivated in industrial areas (e.g., Narsingdi district) of Bangladesh to assess the potential health hazards. Atomic absorption spectroscopy (AAS) served to determine the concentrations of lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) in vegetable samples ($n=72$). The contents of Pb, Cd, Cr, and Ni were found in most of the analyzed vegetables, whereas 79.17%, 44.44%, and 1.39% samples exceeded the FAO/WHO maximum allowable concentration (MAC) for Pb, Cd, and Ni, respectively. The estimated daily intake (EDI) of single heavy metal was below the corresponding maximum tolerable daily intake (MTDI). The incremental lifetime cancer risk (ILCR) values of Cd in all samples exceeded the threshold limit ($\text{ILCR} > 10^{-4}$) for both adults and children, indicating lifetime cancer risk due to the consumption of contaminated vegetables. The target hazard quotient (THQ) of each heavy metal was $\text{THQ} < 1.0$ (except Ni in few samples), indicating that consumers have no non-cancer risk when exposed to a single heavy metal. However, hazard index (HI) values of heavy metals were greater than unity in contaminated WC and AW for adults and children. Meanwhile, WC, AW, and SP samples for children emerged as potential health risks of inhabitants in the studied areas. The outcomes of the present investigation might assist the regulatory bodies concerned in setting new strategies through monitoring the quality of marketed vegetables to minimize the risks to humans.

Keywords Heavy metal · Vegetables · Cancer risk · Target hazard quotient (THQ) · Food safety

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Farzana Akter Laboni and Md. Wadud Ahmed contributed equally.

✉ Islam Md Meftaul
mdmeftaul.islam@uon.edu.au

✉ Md. Sirajul Islam Khan
sirajsau@sau.edu.bd

Md. Wadud Ahmed
wahmed@sau.edu.bd

Aney Parven
aney.parven@uon.edu.au

Md. Fahad Jubayer
fahadbau21@hotmail.com

Md. Aminur Rahman
md.aminur.rahman@uon.edu.au

[1] Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh

[2] Department of Agricultural Engineering, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh

[3] Bangladesh Agricultural Research Council, Dhaka 1215, Bangladesh

[4] Global Centre for Environmental Remediation (GCER), College of Engineering, Science and Environment, The University of Newcastle, Callaghan, NSW 2308, Australia

[5] Department of Food Engineering and Technology, Sylhet Agricultural University, Sylhet 3100, Bangladesh

Introduction

Urban expansion is occurring at a quicker pace than ever before, particularly in the world's least developed countries, resulting in the deposition of several toxic contaminants in the environment through anthropogenic activities [1, 27]. The contamination of soil with hazardous metals is prevalent in urban and peri-urban areas due to municipal and industrial (textile, garment, pharmaceuticals, and cosmetics) operations along with extensive use of agrochemicals [1, 25]. Furthermore, wastewater irrigation is one of the main sources of soil contamination in urban areas [23]. In Bangladesh, wastewater and industrial effluents are recklessly released into neighboring waterways without sufficient treatment due to uncontrolled industrialization [24]. As a consequence, heavy metals do contaminate river or canal water in many industrial areas of Bangladesh [1]. Moreover, farmers prefer to irrigate their agricultural fields with industrial wastewater as it contains N, P, Mg, and K, but they are unaware of the severity of heavy metal poisoning through crop intake [14].

Heavy metals are considered as micronutrients, requiring only a minimal quantity for plant and animal growth [15]. However, regular intake of several heavy metals like Pb, Cd, Cr, and Ni may result in serious health risks even at low concentrations [11, 47]. Chronic exposure to these hazardous metals via contaminated vegetables leads to their accumulation in the liver, kidneys, and other parts of the human body and causes DNA damage,disruption of various biochemical processes; neurological, cardiovascular, and bone diseases; and eventually cancer [1]. Several anthropogenic activities contribute to the accumulation of heavy metals in soil, which are then transmitted to the edible parts of plants [19]. Consequently, the consumption of such vegetables grown in contaminated areas is regarded as one of the principal routes of heavy metal toxicity into the human body [44].

Vegetables are an essential and frequently consumed food, which contain vitamins, minerals, and numerous bioactive components [50]. Regrettably, due to unplanned industrialization in developed and emerging economies such as Bangladesh, vegetables cultivated in these places are contaminated with carcinogenic heavy metals via the water–soil–crop pathway, making it a major and frightening concern [2, 7]. The study area (Narsingdi district) is well-known for its numerous textile industries, the majority of which discharge their effluents into the neighboring Meghna or Shitalakshya rivers [28]. Though several reports revealed the amount of heavy metal contamination in the water of these rivers [31, 41], study on analyses of heavy metal contamination and toxicity in agricultural produces provided seldom attention in the particular areas. Some studies established that vegetables cultivated with industrial effluent content have considerably greater extent of heavy metals in other industrial areas [5, 33, 35, 36]. In particular, Pb, Cd, arsenic (As), mercury (Hg), Cr, and Ni were detected above the threshold limit in fruit and vegetables grown in industrial areas of Bangladesh [2, 39, 44]. The consumption of such heavy metal-contaminated agricultural produce poses a serious threat to public health such as cancer and cardiovascular disease, etc. [39, 44]. Therefore, respective authorities must monitor the hazardous metal concentrations in vegetables cultivated in industrial areas to determine the potential health concerns. Consequently, the current study analyzed the concentrations of toxic Pb, Cd, Cr, and Ni in widely consumed vegetables to protect human health from the detrimental effect of such hazardous metals.

Materials and Methods

Chemicals

Certified reference materials (CRM) of Pb, Cd, Cr, and Ni and chemicals were purchased from Merck (Darmstadt, Germany) through the Bangladesh Scientific and Chemical Company Pvt. Ltd., Dhaka, Bangladesh. All other chemicals and reagents including nitric acid (HNO_3), hydrochloric acid (HCl), hydrogen peroxide (H_2O_2), lead nitrate ($Pb(NO_3)_2$), zinc nitrate ($Zn(NO_3)_2$), chromium oxide (Cr_2O_3), manganese powder (Mn), ammonium chloride (NH_4Cl), and cadmium nitrate ($Cd(NO_3)_2$) were of analytical grade.

Collection and Preparation of Vegetable Samples

In total of seventy-two vegetable ($n=72$) samples were collected from Shibpur ($n=36$) and Raipura ($n=36$) Upazila of Narsingdi district, Bangladesh (Figure S1). For each vegetable, six (6) samples (2 kg each) were collected from six (6) different sellers in one Upazila to cover representative areas. Edible portions of WC (leaf and stem), RA (leaf and stem), AW (leaf and stem), SP (leaf), CF (inflorescence), and EP (fruit) were selected randomly from local markets and cleaned twice with deionized water to remove any adhering soil. Then, the vegetable samples were put into separate ziplock poly bags and transferred to the Department of Agricultural Chemistry laboratory at Sher-e-Bangla Agricultural University in Dhaka, Bangladesh. The detailed information concerning these vegetable samples is presented in Table S1. Twelve samples of each vegetable were processed separately. Small chunks of the air-dried edible components of vegetable samples were dried at 65 °C in an electric oven until they reached a constant weight [33]. The dried vegetable samples were crushed to prepare a fine powder using a porcelain mortar to avoid contamination, put into ziplock poly bags [21], and taken to the analytical laboratory of Bangladesh Agricultural Research Institute, Gazipur, for the determination of Pb, Cd, Cr, and Ni. All samples were stored in a desiccator until required to complete the experiments.

Sample Digestion and Analysis

Ground vegetable samples (0.5 g) were digested with 10 mL nitric acid and 2 mL H_2O_2 at 120–125 °C in a microwave-assisted digestion system [39]. The digested samples were then cooled at room temperature and diluted to 50 mL with deionized water and passed through a 0.45-µm syringe filter (cellulose acetate, Minisart) to a 10-mL plastic bottle. The concentration of heavy metals in the acidic solution was determined using an atomic absorption spectrophotometer (AAS) (Agilent, USA, Model No. FS 240). A calibration curve was prepared using working standard solutions for individual certified reference material (CRM) at different concentrations. Then, the response of the unknown metal ions of the vegetable samples was calculated using the individual calibration curve. The measurements were carried out with flame atomization settings, where the Deuterium lamp served as a background correction. The wavelength of 217, 228.8, 357.9, and 232 nm (sourced from hollow cathode lamp) was selected for Pb, Cd, Cr, and Ni content, respectively, and air acetylene was used as fuel gas. Triplicates ($n = 3$) of each vegetable sample were used for the determination of heavy metal concentration, and the average values were recorded. Initially, the analyzed heavy metal concentrations of vegetable samples were obtained on a dry weight (dw) basis and then converted to the fresh weight (fw) basis for further application.

Method Validation and Quality Control

The method was validated based on the parameters of linearity, coefficient of determination (R^2), lowest of detection (LOD), accuracy, and precision. The calibration curves of Pb, Cd, Cr, and Ni were obtained using standard solutions of six concentrations (0.0–1.0 mg L^{-1}) in deionized water with good linearity ($R^2 = 0.995$). One g of powdered sample was randomly selected and spiked with three distinct heavy metal concentrations (1.0, 1.5, and 2.0 mg L^{-1}) and run in with the AAS. The same procedure was followed for blank/unspiked samples, and deionized water was employed throughout the analysis. The recovery percentages were ranged from 90 to 110% using the known spiked sample with RSD < 10%. The LOD of AAS was obtained for each metal from the three standard deviations of the blank responses. Thus, the LOD of AAS for Pb, Cd, Cr, and Ni was determined to be 0.006, 0.008, 0.01, and 0.0012 mg L^{-1}, respectively, which seems that the AAS was good enough to determine the lower level of tested metal concentration.

Data Analysis

Single-Factor Pollution Index (PI)

The PI is the ratio of heavy metal content in a sample and the permissible limits imposed by international organizations such as the WHO, FAO, and US Environmental Protection Agency (US EPA) [1, 20]:

$$PI = C_V / C_L \tag{1}$$

where C_V is the concentration of heavy metal in vegetable sample (mg kg^{-1}) and C_L is the regulatory limit by FAO/WHO (mg kg^{-1}). PI < 1 indicates samples have not yet been polluted, whereas a value of PI > 1 suggests contamination, and PI = 1 indicates critical condition (require environmental monitoring) [20].

Average Pollution Index (PIA)

The average pollution index (PI_A) of different vegetable samples was calculated as follows [1]:

$$PI_A = \frac{1}{n}\sum_{i=1}^{n} PI \tag{2}$$

where PI is the single-factor pollution index and n is the number of heavy metal species studied. $PI_A > 1.0$ suggests higher heavy metal contamination is evident in the sample [34].

Metal Pollution Index (PIM)

The PI_M is used to observe the total heavy metal concentrations in vegetables, which were calculated by using the geometrical mean of all metal concentrations in the samples [42]:

$$PI_M = (C_1 \times C_2 \times C_3 \times \ldots \ldots \cdots \times C_n)^{1/n} \tag{3}$$

where C_n = heavy metal concentration in the n^{th} sample (mg kg^{-1}).

Estimated Daily Intake of Heavy Metal

The consumer health risk is assessed by obtaining the estimated daily intake (EDI) value and comparing it with the maximum tolerable daily intake (MTDI) set by regulatory bodies. According to the US EPA, the EDI values of different heavy metals were estimated as follows [29, 32]:

$$EDI = \frac{VIR \times C}{BW} \tag{4}$$

where VIR = vegetable ingestion rate (in kg) of Bangladesh, C = mean concentration of heavy metal in the sample (mg kg^{-1}), and BW = body weight (kg). The average vegetable ingestion rate in Bangladesh was considered to be 0.1673 kg $person^{-1}$ day^{-1} and BW values of 60 and 32 kg for adults and children, respectively [1, 16].

Health Risk Assessment

Both carcinogenic and non-carcinogenic risks of heavy metals in vegetable samples were estimated using the US EPA models 48.

Carcinogenic Risk

The Incremental Lifetime Cancer Risk (ILCR) is determined to evaluate the possibility of cancer risk through the intake of carcinogenic heavy metals via foodstuffs which were estimated as follows [19]:

$$ILCR = CDI \times CSF \tag{5}$$

where CDI = chronic daily intake of heavy metals (mg kg^{-1} BW day^{-1}) and CSF = cancer slope factor (mg kg^{-1} day^{-1}). According to OEHHA, [30], the oral CSF values of Pb and Cd are 0.0085 and 15 (mg kg^{-1} day^{-1}), respectively. The CDI value for each heavy metal was calculated using the following equation:

$$CDI = \frac{(EDI \times EF \times TED)}{AT} \tag{6}$$

where EDI = estimated daily intake of heavy metal (mg kg^{-1} day^{-1}); EF = exposure frequency (365 days $year^{-1}$); TED = total exposure duration (70 years), which is the average lifetime of Bangladeshi people; and AT = average exposure time (365 days × 70 years = 25,550 days). The cumulative ILCR (ΣILCR) is used to assess total cancer risk due to ingestion of multiple heavy metals by a specific type of food:

$$\sum_{i=1}^{n} ILCR = ILCR_1 + ILCR_2 \ldots\ldots\ldots\ldots\cdots + ILCR_n \tag{7}$$

where i (= 1, 2.....n) is the individual heavy metal present in the same sample. If the estimated ILCR < 10^{-6}, the exposure to people is considered as safe (negligible/accepted risk), whereas ILCR > 10^{-4} is considered as the threshold risk limit (risk requires remedial measures), and ILCR > 10^{-3} is reflected as moderate risk (concerning public health) [14].

Non-carcinogenic Risk

The target hazard quotient (THQ) is used to assess the non-carcinogenic risks of specific heavy metals detected in the sample, which was calculated following the formula [32, 45]:

$$THQ = \frac{CDI}{RfD} \tag{8}$$

where CDI = chronic daily intake of heavy metals (mg kg^{-1} BW day^{-1}) and RfD = oral reference doses of heavy metals (mg kg^{-1} day^{-1}). The standard RfD values of Pb, Cd, Cr, and Ni are 0.0035, 0.003, 1.5, and 0.02 mg kg^{-1} day^{-1}, respectively [1, 16, 39].

The chronic hazard index (HI) is the cumulative target hazard quotient of each heavy metal present in a sample. According to USEPA [48], HI is obtained as follows:

$$\mathrm{HI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{THQ} \tag{9}$$

where i (= 1, 2......., n) = individual heavy metal present in the sample. The exposed population is deemed safe when HI < 1, whereas HI > 1 indicates a potential risk of ingesting contaminated food items. Thus, control measures should be applied [26, 40].

Statistical Analysis

Descriptive statistics of heavy metal concentrations were obtained utilizing MS Excel 2016 version. The obtained results were presented as mean ± standard deviation (SD). In addition, a one-sample t test was performed to check the significant difference (< 0.05) between mean heavy metal concentration and FAO/WHO permissible limit.

Results and Discussion

Heavy Metal Concentration in Vegetable Samples

The concentrations (mean) of heavy metals (Pb, Cd, Cr, and Ni) (mg kg^{-1}, in fresh weight basis) in different vegetable samples are presented in Table 1. The concentration (mean ± SD) of heavy metals in all samples varied significantly ($p < 0.05$) from the corresponding maximum allowable concentrations (MAC). The content of Pb in most vegetable samples exceeded the FAO/WHO safe limit of 0.1 mg kg^{-1}. The order of difference from the corresponding safe consumption limit was Pb > Cd > Ni > Cr. Any variation in the heavy metal concentration in different vegetable

Table 1 Heavy metal concentration (mg kg^{-1}, in fresh weight basis) in different vegetables collected from Narsingdi district, Bangladesh

Sample ID	Heavy metals, mean ± SD (range)			
	Pb	Cd	Cr	Ni
WC ($n = 12$)	$0.38^{a} \pm 0.07$ (0.28–0.47)	$0.06^{b} \pm 0.01$ (0.05–0.09)	$0.24^{c} \pm 0.11$ (0.09–0.39)	$5.80^{d} \pm 0.83$ (4.53–7.27)
RA ($n = 12$)	$0.18^{a} \pm 0.09$ (0.06–0.31)	$0.05^{b} \pm 0.01$ (0.03–0.06)	$0.05^{c} \pm 0.02$ (0.02–0.07)	$1.72^{d} \pm 0.25$ (1.45–2.34)
AW ($n = 12$)	$0.31^{a} \pm 0.05$ (0.23–0.38)	$0.04^{b} \pm 0.01$ (0.04–0.07)	$0.17^{c} \pm 0.02$ (0.13–0.21)	$7.59^{d} \pm 1.64$ (5.26–11.13)
SP ($n = 12$)	$0.15^{a} \pm 0.08$ (0.05–0.25)	$0.11^{b} \pm 0.02$ (0.01–0.09)	$0.15^{c} \pm 0.01$ (0.12–0.17)	$2.53^{d} \pm 0.23$ (2.25–2.95)
CF ($n = 12$)	$0.17^{a} \pm 0.12$ (0.04–0.37)	$0.01^{b} \pm 0.0$ (0.01–0.02)	$0.06^{c} \pm 0.01$ (0.04–0.07)	$1.31^{d} \pm 0.80$ (0.82–1.65)
EP ($n = 12$)	$0.14^{a} \pm 0.11$ (0.02–0.29)	$0.03^{b} \pm 0.01$ (0.01–0.04)	$0.14^{c} \pm 0.02$ (0.12–0.19)	$2.68^{d} \pm 0.94$ (0.75–4.01)
MAC*	0.1	0.05	2.3	10
Samples exceeded MAC (%)	79.17	44.44	0	1.39

*FAO/WHO [10], Proshad et al. [33]; Reg. (EC).1881 [9], Shaheen et al. [39],superscript letters in a column indicates significant difference from MAC ($p < 0.05$); *MAC*, maximum allowable concentration

species depends on climatic change, growth kinetics, accumulation, absorption capacity of plants, and concentrations of heavy metals in soil and irrigation water [14, 33].

The Pb concentrations in different vegetable samples varied from 0.06 to 0.46 mg kg^{-1} with the mean of 0.221 ± 0.10 mg kg^{-1}, whereas the average minimum and maximum concentrations were found in EP (0.14 mg kg^{-1}) and WC (0.38 mg kg^{-1}), respectively. Out of six analyzed vegetable samples, WC (0.380 ± 0.07), RA (0.175 ± 0.09), and AW (0.311 ± 0.05) samples showed significantly higher Pb concentrations, whereas a threefold higher concentration than the MAC (0.1 mg kg^{-1}) was obtained in WC (0.380 ± 0.07) and AW (0.311 ± 0.05). We found that about 67% of RA, EP, CF, and SP samples and 100% of WC and AW samples exceeded the MAC. Alarmingly, around 79.17% of total samples contained higher Pb than the MAC. However, the range of Pb concentration in this study is lower than the other industrial areas of Bangladesh reported in previous studies [6, 16, 17, 39]. Several studies reported the Pb concentration of 22 mg kg^{-1} in watercress [44], 6.04 mg kg^{-1} in varieties of vegetables [3], 0.643–3.362 mg kg^{-1} in a wide range of vegetables grown in different industrial areas of Bangladesh. The Pb concentration (mean) in SP, CF, and RA was reported to be 0.33, 0.51, and 0.19 mg kg^{-1} in the Jhenaidah district by Islam et al. [18] which is 2.35, 3.0, and 1.12 times higher than this study. Pb content above the threshold limit was also reported in different vegetables collected from industrial areas of Nigeria (0.072 ± 0.06 to 0.128 ± 0.03 mg kg^{-1}), [43], Ethiopia (3.63 to 7.56 mg kg^{-1}) [13], Libya (0.02 to 1.824 mg kg^{-1}) [8], Brazil (0.04 to 1.10 mg kg^{-1}) [12], India (0.07–0.13 mg kg^{-1} [42, 49], Pakistan (3.98 ± 2.29 mg kg^{-1}) [15], and Turkey (0.9 to 2.6 mg kg^{-1}) [38]. Cd concentrations in all the analyzed vegetables were ranged from 0.006 to 0.138 mg kg^{-1}, with the highest mean value occurring in SP (0.114 mg kg^{-1}) and the least in CF (0.013 mg kg^{-1}). The Cd content was significantly lower in RA (0.048 ± 0.01), AW (0.044 ± 0.01), CF (0.013 ± 0.0), and EP (0.029 ± 0.01) samples, whereas WC (0.064 ± 0.01) and SP (0.114 ± 0.02) samples had significantly higher Cd content than FAO/WHO MAC (0.05 mg kg^{-1}). It was found that about 17% AW, 58% RA, 92% WC, and 100% SP samples exceeded the safe limit of Cd content. In average, about 44.44% of vegetable samples were contaminated with Cd, which was higher than the threshold value (0.05 mg kg^{-1}). Islam et al. [18] found the Cd concentration as 0.48, 0.3, and 0.23 mg kg^{-1} in SP, CF, and RA in the Jhenaidah district which is 4.36, 23, and 4.79 times greater than the current study. The maximum Cd concentration (mean) of different vegetables was ranged from 0.13 to 0.57 mg kg^{-1}, reported in varieties of vegetables collected from industrial areas in Dhaka [4, 45], [2] Gazipur (0.08 to 0.15 mg kg^{-1}) [45], Tangail (1.86 ± 0.64 mg kg^{-1}) [33], Sathkhira (0.05 to 1.05 mg kg^{-1}) [46], and Jessore (0.24 to 0.77 mg kg^{-1}) [6], districts of Bangladesh. Some other studies also reported the over concentration of Cd in food products in other developing countries [11, 37, 43]. The average Cr concentration in different investigated vegetable samples was 0.135 ± 0.10 mg kg^{-1} (range 0.019 to 0.39 mg kg^{-1}), whereas the average minimum and maximum concentration was detected in RA (0.054 mg kg^{-1}) and WC (0.24 mg kg^{-1}), respectively, and the concentrations were significantly lower than the FAO/WHO MAC (2.3 mg kg^{-1}). According to FAO/WHO guidelines, the Cr concentration in collected vegetable samples from industrial areas of the Narsingdi district of Bangladesh indicated negligible or no risk to human health. However, the leafy vegetable samples, WC (0.241 ± 0.11), and SP (0.146 ± 0.01) showed higher Cr accumulation than others. Cr concentrations were reported in the range of 0.56–23.6 mg kg^{-1} [3] and 0.01–10 mg kg^{-1} [44] for different vegetable samples from Gazipur industrial areas, whereas lower than MAC was also reported for

Fig. 1 Single-factor pollution index of heavy metals in different vegetables grown in industrial areas of Bangladesh

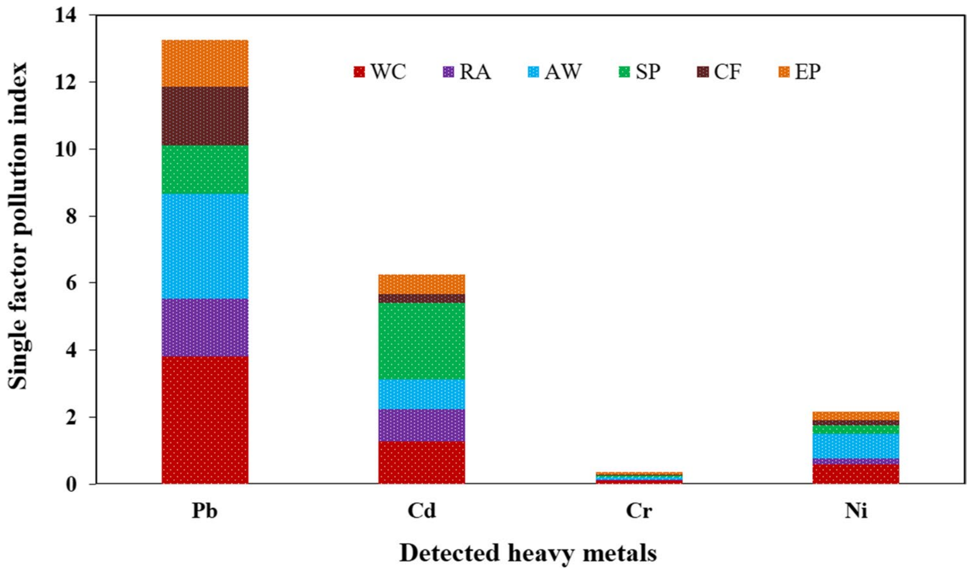
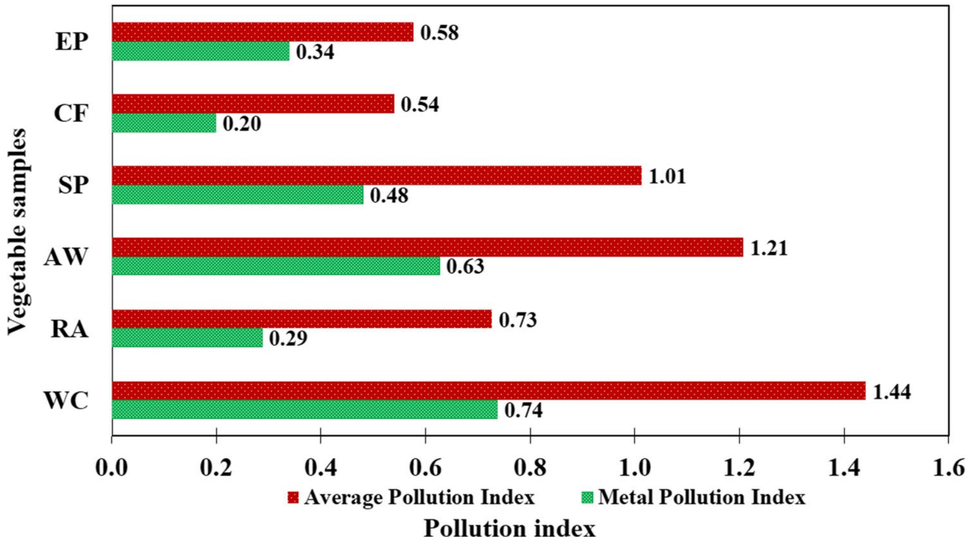


Fig. 2 Comparison between average pollution index and metal pollution index in different vegetable samples



vegetable samples collected from Faridpur industrial areas [14] and local markets in the capital city, Dhaka [22].

The Ni concentrations were ranged from 0.74 to 11.13 mg kg^{-1}, and most of the samples were found within the safe consumption limits as per MAC (10 mg kg^{-1}) set by FAO/WHO, except one sample of AW, which contained 11.13 mg kg^{-1} Ni. The mean concentration of Ni was 3.605 ± 2.5 mg kg^{-1}. The maximum Ni concentration (11.13 mg kg^{-1}) was found in the AW sample, whereas the lowest Ni content (0.748 mg kg^{-1}) was recorded in the EP samples. The mean Ni concentration in vegetable samples was in the following order: AW > WC > EP > SP > RA > CF. A comprehensive study on heavy metal concentration of Bangladeshi vegetables revealed the Ni concentration in the range of 0 to 11.33 mg kg^{-1} in industrial site vegetables [44] and 1.41 to 26.30 mg kg^{-1} in the fruit vegetables [33]. It is evident from the above discussion that Pb concentrations were higher than the FAO/WHO safe limit in all six types of vegetable samples, while Cd concentration is higher only in SP samples.

Pollution Index

The single-factor pollution index varied greatly between vegetable samples (Fig. 1). In case of Pb concentration, all samples exceeded the threshold value (PI > 1.0), indicating elevated contamination with this carcinogenic metal. The highest PI value (3.801) was observed in WC, while the lowest was in EP (1.40) samples, respectively. The pollution assessment of Cd confirmed that only WC (1.28) and SP (2.28) samples exceeded the acceptable value (PI > 1.0). However, all the analyzed vegetable samples showed PI < 1.0

Table 2 Estimated daily intake (EDI) of heavy metals in contaminated vegetables and corresponding maximum tolerable daily intake (MTDI)

Estimated daily intake (EDI) (mg kg^{-1} day^{-1})								
Sample	Pb		Cd		Cr		Ni	
	Adult	Children	Adult	Children	Adult	Children	Adult	Children
WC	1.1×10^{-3}	2.0×10^{-3}	1.8×10^{-4}	3.3×10^{-4}	6.7×10^{-4}	1.3×10^{-3}	1.6×10^{-2}	3.0×10^{-2}
RA	4.9×10^{-4}	9.1×10^{-4}	1.3×10^{-4}	2.5×10^{-4}	1.5×10^{-4}	2.8×10^{-4}	4.8×10^{-3}	9.0×10^{-3}
AW	8.7×10^{-4}	1.6×10^{-3}	1.2×10^{-4}	2.3×10^{-4}	4.7×10^{-4}	8.9×10^{-4}	2.1×10^{-2}	4.0×10^{-2}
PS	4.0×10^{-4}	7.6×10^{-4}	3.2×10^{-4}	6.0×10^{-4}	4.1×10^{-4}	7.6×10^{-4}	7.1×10^{-3}	1.3×10^{-2}
CF	4.8×10^{-4}	9.1×10^{-4}	3.7×10^{-5}	6.9×10^{-5}	1.7×10^{-4}	3.2×10^{-4}	3.6×10^{-3}	6.8×10^{-2}
EP	3.9×10^{-4}	7.3×10^{-4}	8.1×10^{-5}	1.5×10^{-4}	3.9×10^{-4}	7.3×10^{-4}	7.5×10^{-3}	1.4×10^{-2}
Total EDI	0.004	0.007	0.001	0.002	0.002	0.004	0.06	0.113
MTDI*	0.21		0.02–0.07		0.04–0.2		0.1–0.3	

*Proshad et al. (2019) [33] ;Shaheen et al. [39]

for Cr and Ni contamination. It was observed that the lowest or highest values of both indexes (average pollution index and metal pollution index) were obtained in the same sample (Fig. 2). The WC (0.74) revealed the highest PI_M among the six vegetables samples, followed by AW (0.63), SP (0.48), EP (0.34), RA (0.29), and CF (0.19), respectively. The $PI_A > 1.0$ in WC (1.44), AW (1.21), and SP (1.01) suggest the potential pollution hazard is real due to the accumulation of heavy metals.

Estimated Daily Intake of Heavy Metal

The most common route of heavy metal exposure in the human body occurs through the consumption of food. The severity of the associated risk depends on the intake rate of heavy metals through contaminated foods. In this study, the EDI values of Pb, Cd, Cr, and Ni for adults and children were calculated and compared with MTDI (Table 2). The total EDI values of Pb, Cd, Cr, and Ni for adults were 0.004, 0.001, 0.002, and 0.006 mg kg^{-1} day^{-1}, while the corresponding values for children were 0.007, 0.002, 0.004, and 0.113, respectively. Among all the heavy metals, Ni and Pb have the highest EDI values for both adults and children groups. However, the calculated EDI values of any heavy metal in a single or all studied samples were lower than the corresponding MTDI.

Health Risk Assessment

Cancer Risk

Pb and Cd are classified as carcinogenic heavy metals as their chronic exposer causes different types of cancer [14]. The calculated incremental lifetime cancer risks (ILCRs) of Pb and Cd via consuming contaminated vegetables are presented in Table 3. The calculated ILCRs of Pb and Cd ranged from 4.1×10^{-6} to 3.3×10^{-6} and 7.8×10^{-6} to 1.7×10^{-5} and 5.5×10^{-4} to 4.8×10^{-3} and 1.0×10^{-3} to 9.0×10^{-3} for adults and children, respectively. These findings demonstrated that the cancer risk of Cd in all the analyzed vegetables is higher than the threshold value ($ILCR > 10^{-4}$), which poses a potential cancer risk to both target groups (children and adults). In contrast, the least cancer risk was observed from Pb, which exceeded the safe limit ($ILCR > 10^{-6}$) but within the acceptable limit (ranged between 10^{-6} and 10^{-4}). The sum ILCR values of analyzed vegetables for children and adults are depicted in the following order: SP > AW > RA > AW > EP > CF. Moreover, the cancer risk of some leafy and root vegetables grown in other industrial areas of Bangladesh has been reported in the literature, which exceeded the threshold value [14, 39, 40, 44].

Non-cancer Risk

The non-cancer risk of heavy metals in six vegetables for adults and children was estimated based on target hazard quotient (THQ) and hazard index ($HI = \Sigma THQ$), which are displayed in Table 3 and Fig. 3. In general, THQ values of Pb, Cd, Cr, and Ni in most of the vegetable samples were $THQ < 1.0$, implying no detrimental health effect to exposed consumers experienced no damage to their health (Table 3). The value of $THQ > 1.0$ was observed only for Ni (1.1 and 2.0) in the investigated AW sample for adults and children, respectively, indicating severe non-cancer risk to both consumers groups. The highest TTHQ was obtained for Ni ($TTHQ = 3$ in adults, 5.7 in children), and the trend that emerged was Ni > Pb > Cd > Cr for both aged groups. The cumulative non-cancer risk of all studied heavy metals was expressed as hazard index (HI). The WC (1.2) and AW (1.3) samples revealed the $HI > 1.0$

Table 3 Non-cancer risk as total target hazard quotient (THQ) and incremental lifetime cancer risks (ILCR) of adults and children through consumption of heavy metal-contaminated vegetables

Sample	Non-cancer risk (THQ)										Incremental lifetime cancer risk (ILCR)					
	For adults					For children					For adults			For children		
	Pb	Cd	Cr	Ni	**HI**	Pb	Cd	Cr	Ni	**HI**	Pb	Cd	**Sum**	Pb	Cd	**Sum**
WC	3.0×10^{-1}	5.9×10^{-2}	4.5×10^{-4}	8.1×10^{-1}	1.2	5.7×10^{-1}	1.1×10^{-1}	8.4×10^{-4}	$1.5\times10^{+0}$	2.2	9.0×10^{-6}	2.7×10^{-3}	2.7×10^{-3}	1.7×10^{-5}	5.0×10^{-3}	5.0×10^{-3}
RA	1.4×10^{-1}	4.5×10^{-2}	1.0×10^{-4}	2.4×10^{-1}	0.4	2.6×10^{-1}	8.4×10^{-2}	1.9×10^{-4}	4.5×10^{-1}	0.8	4.1×10^{-6}	2.0×10^{-3}	2.0×10^{-3}	7.8×10^{-6}	3.8×10^{-3}	3.8×10^{-3}
AW	2.5×10^{-1}	4.1×10^{-2}	3.2×10^{-4}	1.1	1.3	4.6×10^{-1}	7.7×10^{-2}	5.9×10^{-4}	2.0	2.5	7.4×10^{-6}	1.8×10^{-3}	1.9×10^{-3}	1.4×10^{-5}	3.5×10^{-3}	3.5×10^{-3}
SP	1.2×10^{-1}	1.1×10^{-1}	2.7×10^{-4}	3.5×10^{-1}	0.6	2.2×10^{-1}	2.0×10^{-1}	5.1×10^{-4}	6.6×10^{-1}	1.1	3.4×10^{-6}	4.8×10^{-3}	4.8×10^{-3}	6.4×10^{-6}	9.0×10^{-3}	9.0×10^{-3}
CF	1.4×10^{-1}	1.2×10^{-2}	1.1×10^{-4}	1.8×10^{-1}	0.3	2.6×10^{-1}	2.3×10^{-2}	2.1×10^{-4}	3.4×10^{-1}	0.6	4.1×10^{-6}	5.5×10^{-4}	5.5×10^{-4}	7.7×10^{-6}	1.0×10^{-3}	1.0×10^{-3}
EP	1.1×10^{-1}	2.7×10^{-2}	2.6×10^{-4}	3.7×10^{-1}	0.5	2.1×10^{-1}	5.1×10^{-2}	4.9×10^{-4}	7.0×10^{-1}	1.0	3.3×10^{-6}	1.2×10^{-3}	1.2×10^{-3}	6.2×10^{-6}	2.3×10^{-3}	2.3×10^{-3}
TTHQ	1.1	0.3	0.002	3		2	0.5	0.003	5.7							

TTHQ, total target hazard quotient (ΣTHQ); *HI*, hazard index

for adults, whereas HI > 1 was observed in WC (2.2), AW (2.5), SP (1.1), and EP (1.0) for children (Fig. 3). Therefore, the current investigation reveals the potential non-carcinogenic health risk through ingestion of heavy metal-contaminated vegetables grown in industrial areas of Bangladesh.

Study Limitations

This study did not consider other trace metals such as arsenic, antimony, copper, and zinc, and, therefore, future research should include these as well as to estimate the total elemental exposure and their consequential health hazards. Soil and water samples are also required to be thoroughly investigated for actual metal accumulation levels in vegetables.

Conclusion

This current research revealed the heavy metal contamination in vegetables grown in industrial areas of Bangladesh and associated health hazards. The concentration of Pb and Cd was predominant among the four tested metals in widely consumed WC, AW, RA, SP, CF, and EP samples. It was observed that 79.17% and 44.44% of the vegetable samples exceeded the FAO/WHO acceptable limit for Pb and Cd concentrations, respectiv ely. The computed pollution indices showed that WC, AW, and SP had contamination that exceed the FAO's recommended threshold limit. In contrast, the MTDI values were lower than the daily intake of all heavy metals through vegetable consumption. Human health risk assessment of Cd based on ΣILCR values was found to be higher than the threshold limit ($\Sigma\text{ILCR} > 10^{-4}$) for both adults and children, indicating the lifetime cancer risk due to the consumption of Cd-contaminated vegetables. The potential non-cancer risk was also observed from AW and WC samples, and the THQ of each heavy metal was below the threshold limit ($\text{THQ} < 1.0$) (except Ni in few samples), indicating that consumers have no non-cancer risk of analyzed heavy metals (except Ni) when exposed to a single heavy metal. In contrast, the obtained HI values were found to be higher than 1.0 in contaminated WC and AW for adults and children, which represent the non-cancer risk when exposed to all the heavy metals. Therefore, extensive research on heavy metals in all other vegetables growing in the Narsingdi district is recommended, as it significantly increases the intake of these dangerous and toxic metals, endangering the health of biota.

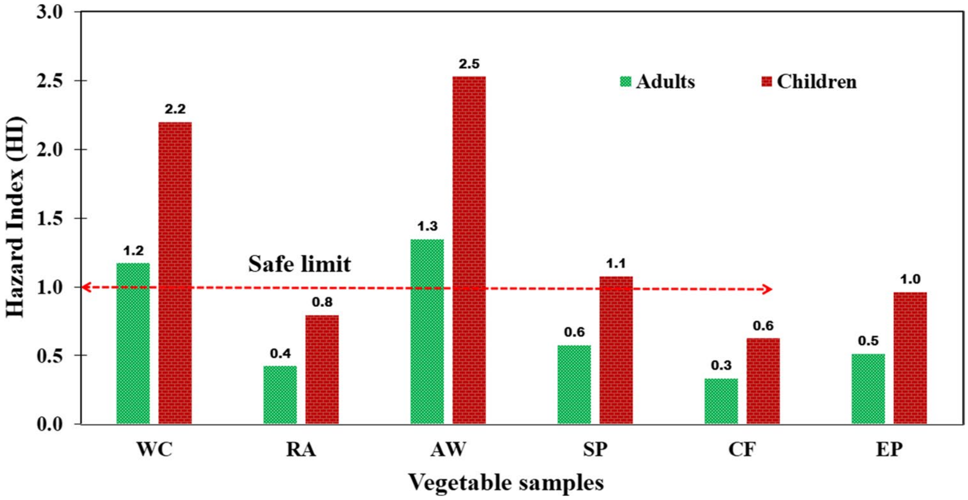


Fig. 3 Non-cancer risk of heavy metals through consumption of contaminated vegetables

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Declarations

Conflict of Interest The authors declare no competing interests.

References

1. Afrin S, Alam MK, Ahmed MW, Parven A, Jubayer MF, Megharaj M, Meftaul IM, Khan MSI (2021) Determination and probabilistic health risk assessment of heavy metals in widely consumed market basket fruits from Dhaka city. Bangladesh International Journal of Environmental Analytical Chemistry 1654. https://doi.org/10.1080/03067319.2021.2018578
2. Ahmad JU, Goni MA (2010) Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh. Environmental monitoring and assessment 166(1):347–357. https://doi.org/10.1007/s10661-009-1006-6
3. Ahmed M, Matsumoto M, Kurosawa K (2018) Heavy metal contamination of irrigation water, soil, and vegetables in a multi-industry district of Bangladesh. International Journal of Environmental Research 12:531–542. https://doi.org/10.1007/s41742-018-0113-z
4. Ahmed S, Siddique MA, Rahman M, Bari ML, Ferdousi S (2019) A study on the prevalence of heavy metals, pesticides, and microbial contaminants and antibiotics resistance pathogens in raw salad vegetables sold in Dhaka. Bangladesh Heliyon 5(2):e01205. https://doi.org/10.1016/j.heliyon.2019.e01205
5. Alam, M. G. M., Snow, E. T., & Tanaka, A. (2003). Arsenic and heavy metal contamination of rice, pulses and vegetables grown in Samta village, Bangladesh. In Arsenic exposure and health effects V (pp. 103–114). Elsevier Science BV. https://doi.org/10.1016/B978-044451441-7/50009-9
6. Ara, M. H., Mondal, U. K., Dhar, P. K., & Uddin, M. (2018). Presence of heavy metals in vegetables collected from Jashore, Bangladesh: human health risk assessment. Journal of Chemical Health Risks, 8(4), 277–287. https://doi.org/10.22034/jchr.2018.544710
7. Divrikli, U., Saracoglu, S., Soylak, M., Elci, L. (2003). Determination of trace heavy metal contents of Green vegetable samples from Kayseri-Turkey by flame atomic absorption spectrometry, Fresenius Environmental Bulletin, 1128–1131.
8. Elbagermi, M. A., Edwards, H. G. M., & Alajtal, A. I. (2012). Monitoring of heavy metal content in fruits and vegetables collected from production and market sites in the Misurata area of Libya. International Scholarly Research Notices, 2012. https://doi.org/10.5402/2012/827645
9. European Commission (2006) Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Union, 364(365–324).
10. FAO/WHO (2019) General standard for contaminants and toxins in food and feed, Reference: XS 193–1995, Joint FAO/WHO Food Standards Programme, Codex Committee, Rotterdam, The Netherlands 6(3):1–198
11. Gómez SN, Marchisio PF, Balverdi MP, Sales AM (2021) Lead, cadmium and arsenic levels and health risk evaluation of marketed chia seeds in Tucumán, Argentina. J Food Compos Anal 103:104093. https://doi.org/10.1016/j.jfca.2021.104093
12. Guerra F, Trevizam AR, Muraoka T, Marcante NC, Canniatti-Brazaca SG (2012) Heavy metals in vegetables and potential risk for human health. Scientia Agricola 69:54–60
13. Hailu Reta, Gebeyehu Leta Danno, Bayissa Amit, Bhatnagar (2020) Levels of heavy metals in soil and vegetables and associated health risks in Mojo area Ethiopia. PLOS ONE 15(1) e0227883-10.1371/journal.pone.0227883
14. Haque MM, Niloy NM, Khirul MA, Alam MF, Tareq SM (2021) Appraisal of probabilistic human health risks of heavy metals in vegetables from industrial, non-industrial

and arsenic-contaminated areas of Bangladesh. Heliyon 7(2):e06309. https://doi.org/10.1016/j.heliyon.2021.e06309

15. Haroon M, Al-Saadi AA, Iqbal MA (2021) Comparative exposure assessment of potential health risks through the consumption of vegetables irrigated by freshwater/wastewater: Gujranwala, Pakistan. Chemical Research in Toxicology. https://doi.org/10.1021/acs.chemrestox.0c00277
16. Hossain MS, Ahmed F, Abdullah ATM, Akbor MA, Ahsan MA (2015) Public health risk assessment of heavy metal uptake by vegetables grown at a waste-water-irrigated site in Dhaka, Bangladesh. Journal of Health and Pollution 5(9):78–85. https://doi.org/10.5696/2156-9614-5-9.78
17. Islam MS, Ahmed MK, Habibullah-Al-Mamun M (2015) Determination of heavy metals in fish and vegetables in Bangladesh and health implications. Hum Ecol Risk Assess Int J 21(4):986–1006. https://doi.org/10.1080/10807039.2014.950172
18. Islam R, Kumar S, Rahman A, Karmoker J, Ali S, Islam S, Islam MS (2018) Trace metals concentration in vegetables of a sub-urban industrial area of Bangladesh and associated health risk assessment. AIMS environmental science 5(3):130–142
19. Kasozi KI, Hamira Y, Zirintunda G, Alsharif KF, Altalbawy FM, Ekou J, ..., Otim O (2021) Descriptive analysis of heavy metals content of beef from Eastern Uganda and their safety for public consumption. Frontiers in Nutrition 8:592340. https://doi.org/10.3389/fnut.2021.592340
20. Kowalska JB, Mazurek R, Gąsiorek M, Zaleski T (2018) Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination–a review. Environ Geochem Health 40(6):2395–2420. https://doi.org/10.1007/s10653-018-0106-z
21. Kumar S, Rahman A, Islam R, Hashem A, Rahman MM (2021) Lead and other elements-based pollution in soil, crops and water near a lead-acid battery recycling factory in Bangladesh. Chemosphere: 133288. https://doi.org/10.1016/j.chemosphere.2021.133288
22. Linkon KMMR, Satter MA, Jabin SA, Abedin N, Islam MF, Lisa LA, Paul DK (2015) Mineral and heavy metal contents of some vegetable available in local market of Dhaka city in Bangladesh. IOSR. J Environ Sci Toxicol Food Technol 9:1–6. https://doi.org/10.9790/2402-09510106
23. Mahmood A, Malik RN (2014) Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore. Pakistan Arabian Journal of Chemistry 7(1):91–99. https://doi.org/10.1016/j.arabjc.2013.07.002
24. Majumder AK, Al Nayeem A, Islam M, Akter MM, Carter WS (2021) Critical review of lead pollution in Bangladesh. Journal of Health Pollution 11(31):210902. https://doi.org/10.5696/2156-9614-11.31.210902
25. Meftaul IM, Venkateswarlu K, Annamalai P, Parven A, Sobhani Z, Megharaj M (2021a) Behavior and fate of fungicide chlorothalonil in urban landscape soils and associated environmental concern. Journal of Environmental Science and Health, Part B, 2014255. https://doi.org/10.1080/03601234.2021.2014255
26. Meftaul IM, Venkateswarlu K, Annamalai P, Parven A, Megharaj M (2021) Glyphosate use in urban landscape soils: fate, distribution, and potential human and environmental health risks. J Environ Manage 292:112786. https://doi.org/10.1016/j.jenvman.2021.112786
27. Meftaul IM, Venkateswarlu K, Dharmarajan R, Annamalai P, Megharaj M (2020) Pesticides in the urban environment: a potential threat that knocks at the door. Sci Total Environ 711:134612. https://doi.org/10.1016/j.scitotenv.2019.134612
28. Miah MD, Islam KN, Kabir MH, Koike M (2020) Allometric models for estimating aboveground biomass of selected homestead tree species in the plain land Narsingdi district of Bangladesh. Trees, Forests and People 2:100035. https://doi.org/10.1016/j.tfp.2020.100035
29. Nisha US, Khan MSI, Prodhan MDH, Meftaul IM, Begum N, Parven A, Shahriar S, Juraimi AS, Hakim MA (2021) Quantification of pesticide residues in fresh vegetables available in local markets for human consumption and the associated health risks. Agronomy 11:1804. https://doi.org/10.3390/agronomy11091804
30. OEHHA. (2009). “Appendix A : hot spots unit risk and cancer potency values,” Calif. Off. Enviromental Heal. Hazard Assess., no. May, pp. 1–5.
31. Palash MAU, Islam MS, Bayero AS, Taqui SN, Koki IB (2020) Evaluation of trace metals concentration and human health implication by indigenous edible fish species consumption from Meghna River in Bangladesh. Environ Toxicol Pharmacol 80:103440. https://doi.org/10.1016/j.etap.2020.103440
32. Parven A, Khan MSI, Prodhan MDH, Venkateswarlu K, Megharaj M, Meftaul IM (2021) Human health risk assessment through quantitative screening of insecticide residues in two green beans to ensure food safety. J Food Compos Anal 103:104121. https://doi.org/10.1016/j.jfca.2021.104121
33. Proshad R, Kormoker T, Islam MS, Chandra K (2019) Potential health risk of heavy metals via consumption of rice and vegetables grown in the industrial areas of Bangladesh. Hum Ecol Risk Assess Int J 26(4):921–943. https://doi.org/10.1080/10807039.2018.1546114
34. Qingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y (2008) Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. Journal of China University of Geosciences 19(3):230–241. https://doi.org/10.1016/S1002-0705(08)60042-4
35. Rahman MM, Alam K (2021) Clean energy, population density, urbanization and environmental pollution nexus: evidence from Bangladesh. Renewable Energy 172:1063–1072. https://doi.org/10.1016/j.renene.2021.03.103
36. Real MIH, Azam HM, Majed N (2017) Consumption of heavy metal contaminated foods and associated risks in Bangladesh. Environ Monit Assess 189(12):1–14. https://doi.org/10.1007/s10661-017-6362-z
37. Rusin M, Domagalska J, Rogala D, Razzaghi M, Szymala I (2021) Concentration of cadmium and lead in vegetables and fruits. Sci Rep 11(1):1–10. https://doi.org/10.1038/s41598-021-91554-z
38. Sesli E, Tuzen M, Soylak M (2008) Evaluation of trace metal contents of some wild edible mushrooms from Black sea region, Turkey. J Hazard Mater 160:462–467. https://doi.org/10.1016/j.jhazmat.2008.03.020
39. Shaheen N, Irfan NM, Khan IN, Islam S, Islam MS, Ahmed MK (2016) Presence of heavy metals in fruits and vegetables: health risk implications in Bangladesh. Chemosphere 152:431–438. https://doi.org/10.1016/j.chemosphere.2016.02.060
40. Shahriar S, Haque MM, Naidu R, Rahman MM (2021) Concentrations of toxic elements and health risk assessment in arum grown in arsenic-contaminated areas of Bangladesh. Food Control 129:108240. https://doi.org/10.1016/j.foodcont.2021.108240
41. Sharma C, Shukla AK, Zhang Y (2021) Climate change detection and attribution in the Ganga-Brahmaputra-Meghna river basins. Geosci Front 12(5):101186. https://doi.org/10.1016/j.gsf.2021.101186
42. Singh A, Sharma RK, Agrawal M, Marshall FM (2010) Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India.

Food Chem Toxicol 48(2):611–619. https://doi.org/10.1016/j.fct.2009.11.041

43. Sobukola OP, Adeniran OM, Odedairo AA, Kajihausa OE (2010) Heavy metal levels of some fruits and leafy vegetables from selected markets in Lagos. Nigeria African Journal of food science 4(6):389–393
44. Sultana MS, Rana S, Yamazaki S, Aono T, Yoshida S (2017) Health risk assessment for carcinogenic and non-carcinogenic heavy metal exposures from vegetables and fruits of Bangladesh. Cogent Environmental Science 3(1):1291107. https://doi.org/10.1080/23311843.2017.1291107
45. Sultana R, Chamon AS, Mondol MN (2021) Heavy metal concentration in commonly sold stem vegetables in Dhaka city market and probable health risk. Dhaka University Journal of Biological Sciences 30(2):221–232. https://doi.org/10.3329/dujbs.v30i2.54648
46. Uddin MN, Hasan MK, Dhar PK (2019) Contamination status of heavy metals in vegetables and soil in Satkhira, Bangladesh. Journal of Materials and Environmental Science 10:543–552
47. Uluozlu OD, Tuzen M, Mendil D, Soylak M (2009) Assessment of trace element contents of chicken products from Turkey. J Hazard Mater 163:982–987. https://doi.org/10.1016/j.jhazmat.2008.07.050
48. USEPA (2001) Risk assessment guidance for superfund: volume III part A, process for conducting probabilistic risk assessment. US Environmental Protection Agency, Washington, DC
49. Verma Y, Rana SVS (2014) Assessment of cadmium, chromium, and copper levels in market fruit samples in Meerut, North India. Toxicological & Environmental Chemistry 96(10):1516–1522. https://doi.org/10.1080/02772248.2015.1029735
50. Zhao L, Zhao X, Xu Y, Liu X, Zhang J, He Z (2021) Simultaneous determination of 49 amino acids, B vitamins, flavonoids, and phenolic acids in commonly consumed vegetables by ultra-performance liquid chromatography-tandem mass spectrometry. Food Chem 344:128712. https://doi.org/10.1016/j.foodchem.2020.128712