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Health Risk Assessment of Heavy Metals in the Leafy, Fruit, and Root Vegetables Cultivated Near Mongla Industrial Area, Bangladesh

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Background: Vegetables are the main source of nutrients for the human being but the intake of contaminated vegetables causes several diseases. Therefore, the aims of this study were to examine heavy metals concentration in leafy, fruit and root vegetables and their growing soil in Mongla, Bangladesh; and to estimate the health risks (non-carcinogenic and carcinogenic) caused by heavy metal exposure through ingestion of vegetable using hazard quotient (THQ) and target cancer risk (TCR).
Methods: United States Environmental Protection Agency (USEPA) deterministic approaches were used to assess the potential health risks to the human.
Results: The average concentration of Fe, Cd, and Pb was 489.47, 0.48 and 8.15 mg/kg respectively, which was above the permissible limit recommended by WHO/FAO. Furthermore, THQ values for these metals and combined impacts of all metals (HI) were greater than the acceptable limit (1.0) which indicated a potential non-carcinogenic health risk. TCR values of Cd and Pb were greater than USEPA risk limit ($>10^{-6}$); which exerts moderate to high carcinogenic risk to the human.
Conclusion: The total health risk index showed that the consumption of vegetables from this study area poses a health risk and therefore regular monitoring of heavy metals is strongly recommended.

1. Introduction

Plants play a key role in human life, while they are also considered to be predominant medicinal sources for the populations in Bangladesh [1]. Vegetables are a major constituent of the human diet owing to the high contents of vitamins, minerals, trace elements, cellulose, hemicellulose, pectin, and fiber [2, 3]. In addition, vegetables are among the main sources of nutrients for humans, playing a pivotal role in the prevention of cancer and reducing the risk of cardiovascular and other chronic diseases [1]. Unfortunately, these essential foods are polluted by heavy metals, and intake of contaminated vegetables might exert deleterious health effects on humans.

Heavy metals are non-biodegradable and could persist for a long time in the environment. When vegetables are cultivated in polluted environments, they could readily absorb heavy metals through the leaves or roots, leading to the accumulation of toxic metals in plant tissues [4]. The entry of heavy metals into the food chain not only inhibits the normal physiological functions of the human body, but it also affects the growth, nutrient uptake, nitrogen fixation, and metabolism of plants [4, 5].

Recently, food safety and hygiene have become a major concern among researchers, and many countries have been applying regular monitoring to establish a database regarding the contamination status of heavy metals in foods, crops, and vegetables.

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In a study, Ara et al. (2018), examined the concentrations of heavy metals in vegetables in Jashore (Bangladesh), reporting that Cd and Pb could pose non-carcinogenic health risks. Moreover, the combined impact of all metals (HI) may be associated with the high risk of non-carcinogenic effect [6]. In a similar research, Islam et al. (2014), determined the concentration of heavy metals in some vegetables in Dhaka (Bangladesh), observing that the concentration of Zn, Cd, and Pb in most vegetables exceeded the food safety standards, and the target hazard quotient (THQ) values showed potential health risks to the local population [7].

According to Shaheen et al. (2016), the concentrations of Cd, Pb, Mn, Cu, and Zn in vegetables were higher than the recommended levels by the Word Health Organization (WHO)/Food and Agriculture Organization (FAO), and the THQ values for Mn and Cu indicated significant health risks for humans. Moreover, the hazard index (HI) value was reported to be higher than 1.0 for vegetable consumption, suggesting adverse health effects on humans [8]. According to Khan et al. (2014), the metal pollution index (MPI) and health risk index (HRI) represented non-carcinogenic risks to human health due to the higher content of Fe in vegetables [9]. In another study, Ahmad et al. (2010), evaluated the concentrations of Cu, Zn, Pb, Cd, and Fe in vegetables and soil in various industrial areas in Bangladesh, reporting that the concentration of Cd in soil and vegetables was higher than the tolerable limit [10]. Similarly, Sultana et al. (2017), claimed that the risk of cancer was higher than the threshold risk limit ($>10^{-4}$) in terms of the Cd concentration recommended by the United States Environmental Protection Agency (USEPA). In addition, the authors stated that Mn, Pb, and Fe represented non-carcinogenic risks, while Cd represented carcinogenic risks [11].

In this regard, the findings of Zhong et al. (2018), indicated that the individuals living in Hubei province (south China) and Liaoning province (northeast China) were exposed to the high risk of Pb and Cd contamination due to the consumption of vegetables [12]. In another study, Luo et al. (2011), monitored the vegetables and soil quality in south China, reporting that the concentrations of Cd and Cu in the soil and Cd and Pb in most vegetables exceeded the maximum level [13]. According to Singh et al. (2010), the THQ value showed the health risks associated with the Cd and Pb contamination of vegetables to the local population in Varanasi (India) [4]. Furthermore, Shakya et al. (2013), concluded that the vegetables collected from various markets in Kathmandu (Nepal) contained elevated levels of Pb and Cd. Therefore, the consumption of vegetables in this region might pose health risks to humans [14]. According to the literature, heavy metal pollution and food safety are not only an alarming issue for Bangladesh, but also all the countries across the world.

Available data is scarce regarding the contamination status of heavy metals in various regions in Bangladesh. Mongla is an industrial area in this country, and most of the people in this region cultivate different types of vegetables, supplying the local markets. Due to rapid industrialization, increased household chores, and inappropriate agricultural practices, the vegetables cultivated in this area are assumed to be contaminated. The consumption of contaminated vegetables might pose severe health risks (non-carcinogenic and carcinogenic) to humans.

The present study aimed to assess the health risks posed to the population in Mongla, Bangladesh due to heavy metal exposure through the ingestion of vegetables based on the health index (HI) and target cancer risk (TCR).

2. Materials and Methods

2.1. Geographical Location and Background of the Studied Area

Mongla is a suburban area in Bagerhat district, located on the bank of Pashur River. It lies between 22°33´-21°49´ north latitudes and 89°32´-89°44´ east longitudes and is surrounded by Rampal Upazila on the north, Morrelgonj and Saronkhola Upazila on the east, the Bay of Bengal on the south, and Dacop Upazila of Khulna District on the west (Figure 1).

Mongla occupies an area of 1461.20 square kilometers, 1083.00 square kilometers of which is Sundarbans Forest. Mongla is a port with 19 industries located in its remaining 378.2 square kilometers. Since it is a coastal belt near the Bay of Bengal, cyclones, heavy rainfalls, and tidal wave hit the area almost every year. During the rainy season, the industrial wastes and domestic sewage are washed away, and cultivated vegetables are often affected by waterlogging. Consequently, heavy metals may accumulate in the agricultural lands, as well as in vegetables.

2.2. Sample Preparation and Heavy Metal Analysis

In this study, three types of leafy vegetables (*Amaranthus gangeticus, Spinacia oleracea*, and *Ipomoea aquatica*), five types of fruit vegetables (*Brassica oleracea, Solanum lycopersicum, Cucurbita pepo, Carica papaya, and Solanum melongena*), two types of root vegetables (*Brassica oleracea* and *Raphanus raphanistrum*), and their soil were randomly collected from 20 sites in Mongla industrial area. The vegetables are locally known as Lal Shak, Palong Shak, Kolmi Shak, Fulkopi, tomato, Misti Kumra, Papa, Begoon, Olkopi, and Mula, respectively.

Analytical-grade reagents (Wako, Osaka, Japan and Merck, Darmstadt, Germany) were purchased from the local market and used without further purification. The vegetables and soil samples were prepared using the acid digestion method. In this method, 15 milliliters of 5:1:1 tri-acid mixture (70% HNO_3, 70% H_2SO_4, and 65% $HClO_4$) was added to each beaker containing one gram of the dry samples. Afterwards, the mixture was subjected to digestion at the temperature of 80°C until a transparent solution was obtained. After cooling, the digested sample was filtered using a Whatman No. 42 filter paper and poured into a Teflon bottle. Finally, the filtrate was diluted to 50 milliliters with deionized water for heavy metal analysis [6, 15]. The solution was prepared immediately using high purity deionized water before the analysis.

An atomic absorption spectrophotometer (Shimadzu model AA-7000, made in Tokyo, Japan) was used for the quantification of heavy metals concentrations (Mn, Fe, Cu, Zn, Pb, and Cd) in the digested soil and vegetable samples. The overall analyses were carried out based on the method described by [6, 16]. In addition, air-acetylene flame (BOC, Jashore, Bangladesh) was applied to determine the presence of all the elements. Before measuring the concentrations of heavy metals (mg/kg), a series of reference standard solutions (0.0-5.0 ppm) were prepared, and standard calibration curves were constructed at the wavelengths of 279.5, 248.3, 213.9, 324.8, 217.0, and 228.8 nanometers [6].

2.3. Health Risk Analysis

In this study, the deterministic model proposed by the USEPA and its threshold values were employed to assess the potential human health risks posed by Mn, Fe, Cu, Zn, Pb, and Cd [17-19]. Moreover, THQ and HI were used to evaluate non-carcinogenic health risks, and TCR was analyzed to determine the possibility of carcinogenic health risks.

2.3.1. Estimated Daily Intake (EDI)

Daily intake of contaminated vegetables is a general pathway of heavy metal exposure for humans. The estimated daily intake (EDI) of heavy metals in the studied food products was calculated using the following equation [6, 20]:

$$\text{EDI} = \frac{C_m \times I_g}{W_b} \tag{1}$$

Where C_m shows the concentrations of heavy metals in the samples (mg/kg of dry weight), I_g denotes the rate of ingestion (0.126 kg/day for vegetables) [21, 22], and W_b represents the average body weight of the consumers. In this study, W_b was considered at 49.5 kilograms in Bangladeshi people [6, 23].

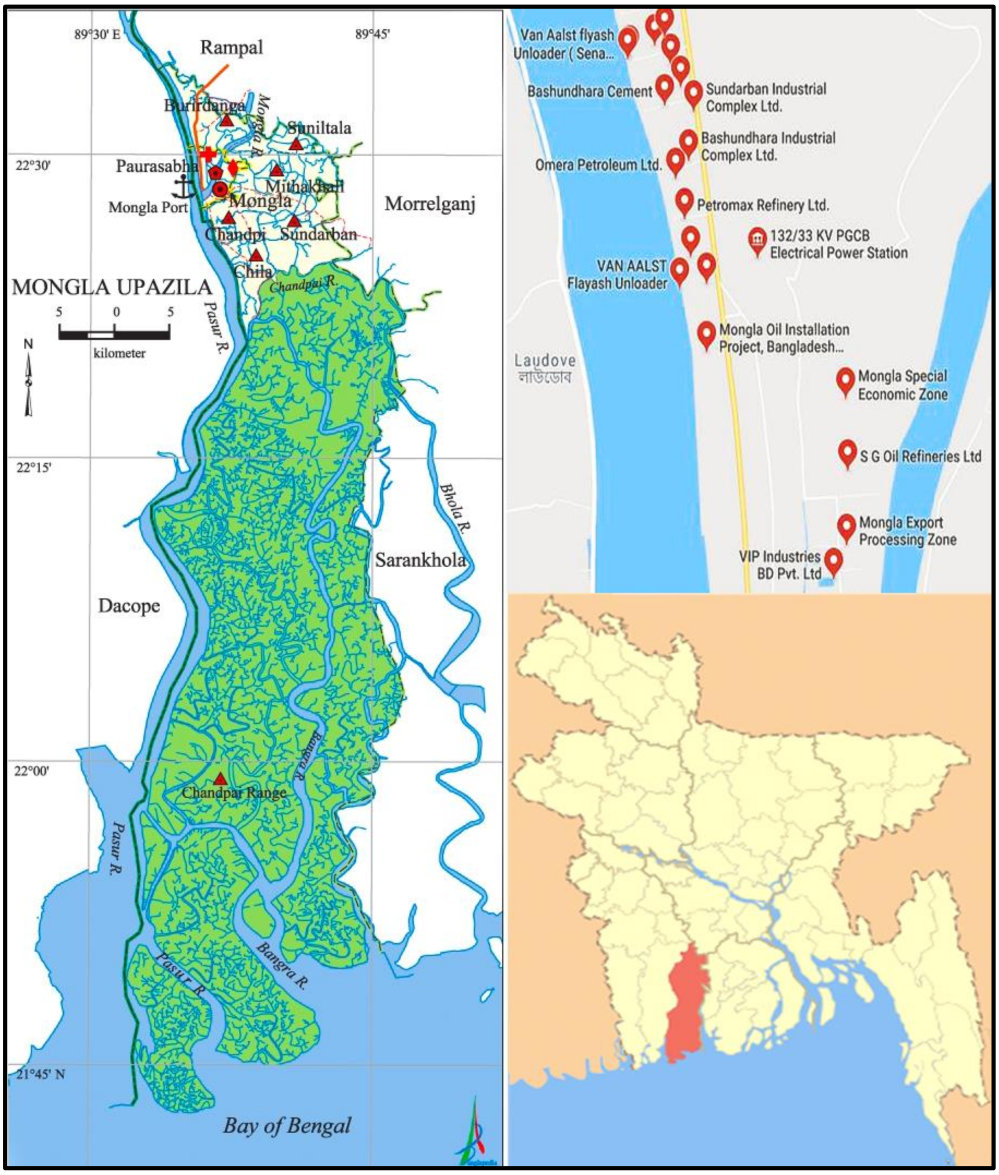

Figure 1: Map of the study area (Mongla industrial area, Bagerhat, Bangladesh)

2.3.2. Target Hazard Quotient (THQ)

THQ was calculated based on the following formula [6, 20]:

$$\mathrm{THQ} = \frac{C_m \times I_g \times E_f \times D_e}{D_f \times W_b \times T_{avncar}} \qquad (2)$$

Where E_f denotes the exposure frequency (365 days/year), D_e is the duration of exposure (71.8 years), D_f represents the reference dose of Fe, Mn, Cu, Zn, Pb, and Cd (0.7, 0.14, 0.04, 0.30, 0.0035, and 0.003 mg/kg/day, respectively) [17], and T_{avncar} shows the average time for non-carcinogens (365 days/year × D_e).

2.3.3. Hazardous Index (HI) and Target Cancer Risk (TCR)

In this study, HI was the sum of the hazard quotients of all the heavy metals, which was calculated based on the following formula [18]:

$$\mathrm{HI} = \sum \mathrm{THQ} = \mathrm{THQ}_{(Mn)} + \mathrm{THQ}_{(Fe)} + \mathrm{THQ}_{(Cu)} + \mathrm{THQ}_{(Zn)} + \mathrm{THQ}_{(Pb)} + \mathrm{THQ}_{(Cd)} \qquad (3)$$

TCR was estimated using the following equation [22]:

$$\mathrm{TCR} = \frac{C_m \times I_g \times E_f \times D_e \times S_{cpo}}{D_f \times W_b \times T_{avncar}} \qquad (4)$$

The reference values of the carcinogenic potency slope (Scpo) of Cd and P_b were determined to be 6.1 and 0.0085 mg/kg/day, respectively [17, 19].

3. Results and Discussion

3.1. Heavy Metal Concentrations in Vegetables

In recent years, food safety and hygiene have become a substantial challenge in developing countries due to the lack of the proper management of the waste materials emitted from industries and other sources. In order to ensure food quality and assess the health risks posed to the consumers, the concentrations of the heavy metals in the commonly consumed vegetables were estimated in this study.

According to the information in Table 1, the concentrations of Mn, Fe, Cu, and Pb (with the exception of Zn and Cd) were higher in leafy vegetables compared to fruit and root vegetables. Furthermore, the highest concentration of Fe was estimated in all types of vegetables and estimated to be 99.25-1661.30 mg/kg depending on the vegetable species. Fe often participates in photosynthesis and chlorophyll synthesis. As a result, leafy vegetables contain higher levels of Fe compared to fruit and root vegetables [23].

Table 1: Average concentration of heavy metals (mg/kg) in vegetables in Mongla, Bangladesh

Sample ID	Mn	Fe	Cu	Zn	Cd	Pb
LS	24.73 10.13 - 41.16	919.84 329.6 - 1661.30	16.95 5.39 - 42.06	30.85 15.08 - 47.87	0.64 0.35 - 0.93	12.22 7.52 - 19.90
PS	31.19 11.11 - 94.42	587.92 125.13 - 1104.4	10.45 1.78 - 25.42	41.00 22.47 - 90.23	0.67 0.52 - 0.98	11.29 8.37 - 14.71
KS	137.57 25.24 - 210.7	606.42 122.08 - 1000.2	14.54 5.23 - 20.18	18.52 11.29 - 24.61	0.36 0.18 - 0.65	6.17 3.15 - 10.52
FK	7.55 3.76 - 13.71	278.49 105.58 - 423.15	3.51 1.79 - 5.67	32.18 12.12 - 45.06	0.14 0.05 - 0.23	2.34 0.80-4.30
TO	26.65 12.04 - 49.12	478.38 99.61- 1476.09	7.08 3.24 - 17.12	31.87 16.52 - 47.22	0.55 0.28 - 0.94	15.54 10.1-31.13
MK	28.95 11.67 - 49.61	752.27 409.91- 1144.3	9.78 3.76 - 17.51	39.62 32.41 - 48.57	0.63 0.34 - 0.95	10.74 8.41-13.99
PP	8.35 2.24 - 13.12	196.93 91.67- 317.05	7.31 2.34 - 11.42	40.98 12.51 - 74.35	0.35 0.05 - 1.15	2.26 0.81 – 4.25
BG	16.58 6.45 - 43.61	499.73 99.5 - 1144.27	11.79 3.62 - 18.43	34.85 17.21 - 48.37	0.13 0.05 - 0.29	1.62 0.49 - 4.25
OK	41.38 11.67 - 99.78	331.72 99.25 - 751.38	7.75 1.08 -13.82	33.39 22.18-51.08	0.67 0.51-0.85	11.00 8.17-14.93
MU	29.45 13.51 - 63.17	242.99 102.72 - 464.41	7.31 1.5 - 11.58	32.59 21.42 - 55.19	0.65 0.5 - 0.94	8.32 0.67-12.65
Av. conc. in leafy vegetables	64.500	704.726	13.979	30.122	0.5568	9.894
Av. conc. in fruit vegetables	17.616	441.615	7.893	35.901	0.3598	6.500
Av. Conc. in root vegetables	35.416	287.356	7.529	32.994	0.6593	9.664
Av. conc. in all vegetables	35.24	489.47	9.65	33.59	0.48	8.15
Range	2.24 - 210.7	99.25 - 1661.30	1.5 - 42.06	11.29 - 90.23	0.05 - 1.15	0.49 - 31.13

In addition, the deposition of Pb was observed to be higher (9.89 mg/kg) in leafy vegetables, while the deposition of Cd was higher in root vegetables (0.659 mg/kg).

The accumulation of higher Cd and Pb levels might be due to the excessive use of inorganic fertilizers, presence of various pesticides and wastewater in agricultural fields, and depositions from vehicle emissions and metal factories [11].

The decreasing sequences of the mean heavy metal concentrations in leafy, fruit, and root vegetables were Fe > Mn > Zn > Cu > Pb > Cd, Fe > Zn > Mn > Cu > Pb > Cd, and Fe > Mn > Zn > Pb > Cu > Cd, respectively. To assess the contamination status of the samples, the mean concentrations of heavy metals were compared with the maximum acceptable limit established by FAO/WHO [24-26], and the concentrations of Fe, Cd, and Pb were found to exceed the permissible limits (Figure 2).

Concentrations of heavy metals in cultivated vegetables vary depending on geographical location and environmental conditions. The obtained results of the study were compared with similar studies, and the concentrations of Mn, Cu, and Zn were observed to be within the permissible limits. Furthermore, most of the studies in the literature have reported that Cd and Pd concentrations tend to exceed the maximum tolerable limits (Table 2).

3.2. Non-carcinogenic and Carcinogenic Health Risks

The non-carcinogenic and carcinogenic health risk parameters were determined using equations 1-4, and the obtained results are presented in Table 3. These parameters have been introduced by the USEPA for estimating the potential health risks caused by chemical contaminants over prolonged exposure [12]. Comparison of the EDI value of each metal with the respective references dose (D_f) showed that the EDI values of Cd and Pb were higher than D_f in all the vegetables, while the EDI value of Fe was higher than the corresponding D_f only in leafy and fruit vegetables.

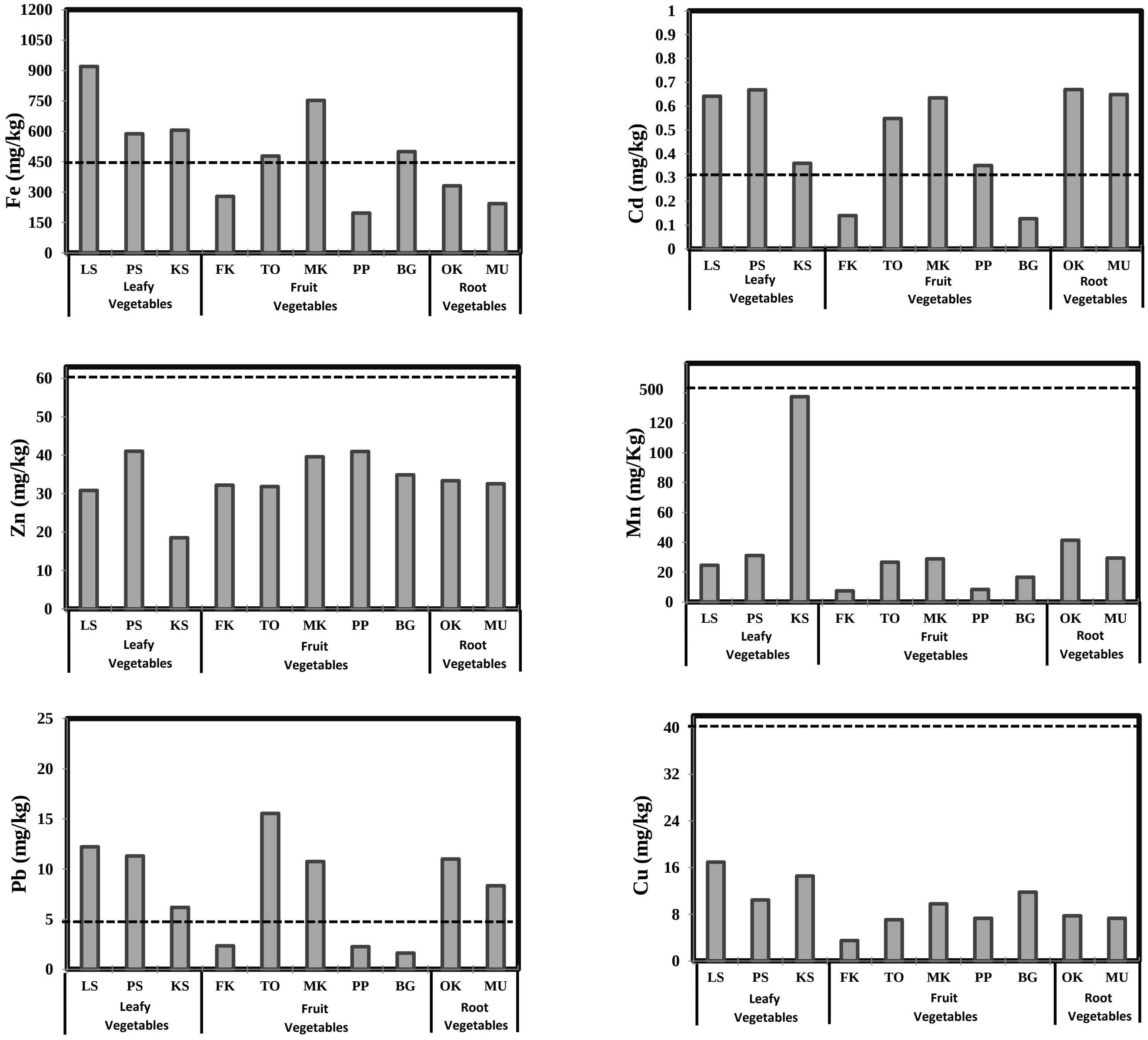

Figure 2: Comparison of the level of heavy metals in vegetables with the standard value [24- 26]

The New York State Department of Health (NYSDOH) has suggested that if the ratio of EDI/D_f is $\leq D_f$, it is associated with minimum health risks. However, if it is >1-5 times higher than D_f, it is associated with low health risks, if it is >5-10 times higher than D_f, it is associated with moderate health risks, and if it is >10 times higher than D_f, it is associated with high health risks [27]. With regard to Pb, the EDI/D_f ratio for all types of vegetables has been reported to be several hundred times greater than the respective D_f, indicating potential health hazards.

THQ is the measure of non-carcinogenic health risks, the acceptable guideline value of which has been reported to be ≤1.0 [21]. In this regard, Ambedkar and Maniyan concluded that if the THQ of each heavy metal elevates its limit, it might be associated with human health risks [28].

In the present study, the THQ values were above 1.0 for Fe (1.81215), Cd (3.34100), and Pb (5.08826) in the leafy vegetables, Cd (3.95550) and Pb (4.96993) in the root vegetables, and Fe (1.13441), Cd (2.15880), and Pb (3.34311) in the fruit vegetables. Therefore, the THQ values of Fe, Cd, and Pb might pose non-carcinogenic risks to the population in the studied area. Furthermore, the combined impact of all the heavy metals (HI) was observed to be higher than the acceptable limit (1.0) in all the vegetables. Therefore, the intake of vegetables in the studied area could be associated with non-carcinogenic health effects [29].

In general, it is assumed that when humans are exposed to more than one pollutant, they may suffer combined or interactive adverse effects [30]. Prolonged exposure to a specific carcinogen may lead to cancer, and the risk increases depending on the contact time. TCR denotes not only an estimation of the expected cancers, but it also represents the possibility of developing carcinogenic risks in an individual [27]. According to the NYSDOH, if the TCR value is $\leq 10^{-6}$, it is associated with low carcinogenic risks, when the value is 10^{-5}-10^{-3}, it is associated with moderate risks, and if the value is 10^{-3}-10^{-1}, it is associated with high risks [27].

Table 2: Comparison of the level (mg/kg dry weight) of heavy metals in vegetables with other similar studies [6]

District (Country)	Mn	Fe	Cu	Zn	Cd	Pb
Jashore	33.297	190.32	9.31	28.23	0.514	5.45
(Bangladesh)	11.33 - 130.18	69.52 - 446.68	1.12 - 30.80	12.52 - 47.76	0.24 - 0.77	0.61 - 14.79
Dhaka	--	1160	17.63	--	0.32	11.48
(Bangladesh)	--	1126 - 1209	10.27 - 29.1	--	0.216 - 0.40	7.32 - 17.0
Rajshahi	4.54	--	--	--	1.05	5.1
(Bangladesh)	1.36 - 8.11	--	--	--	0.15 - 1.75	0.43 - 1.37
Patuakhali	--	--	42.35	--	2.0	8.35
(Bangladesh)	--	--	4.12 - 529.42	--	0.011 - 25.88	0.47 - 103.53
Narayanganj	--	--	9.37	19.76	0.168	3.69
(Bangladesh)	--	--	3.45 - 14.35	12.79 - 27.22	0.095 - 0.283	2.16 - 5.50
Misurata	--	--	3.36	8.15	0.14	0.25
(Libya)	--	--	0.75 - 5.75	0.042 - 16.83	0.02 - 0.27	0.02 - 0.511
Changxing	--	--	--	--	0.035	0.039
(China)	--	--	--	--	0.003 - 0.230	0.003 - 0.178
Varanasi	--	--	22.38	48.62	1.51	1.15
(India)	--	--	9.50 - 56.30	25.20 - 94.30	0.10 - 4.30	0.20 - 2.56
Mongla	35.24	489.47	9.65	33.59	0.48	8.15
(Bangladesh)	2.24 - 210.7	99.25 - 1661.30	1.5 - 42.06	11.29 - 90.23	0.05 - 1.15	0.49 - 31.13

Source: Ara et al. (2018)

Table 3: Estimated daily intake (EDI), target hazard quotient (THQ), hazardous Index (HI mg/kg body weight/day) and target cancer risk (TCR) of leafy, fruit and root vegetables

Parameters	Vegetable types	Mn	Fe	Cu	Zn	Cd	Pb
EDI	Leafy Vegetables	0.05364	1.26851	0.02516	0.05422	0.00100	0.01781
	Fruit Vegetables	0.03171	0.79409	0.01421	0.06462	0.00065	0.01170
	Root Vegetables	0.06375	0.51724	0.01355	0.05939	0.00119	0.01739
THQ	Leafy Vegetables	0.38314	1.81215	0.62905	0.18073	3.34100	5.08826
	Fruit Vegetables	0.22649	1.13441	0.35516	0.21541	2.15880	3.34311
	Root Vegetables	0.45534	0.73892	0.33879	0.19796	3.95550	4.96993
HI	Leafy Vegetables	11.43433	--	--	--	--	--
	Fruit Vegetables	7.43338	--	--	--	--	--
	Root Vegetables	10.65644	--	--	--	--	--
TCR	Leafy Vegetables	--	--	--	--	$6.1E^{-3}$	$1.5E^{-4}$
	Fruit Vegetables	--	--	--	--	$3.9E^{-3}$	$9.9E^{-5}$
	Root Vegetables	--	--	--	--	$7.2E^{-3}$	$1.5E^{-4}$

In the present study, the TCR value of Pb (1.5E $^{-4}$, 9.9E $^{-5}$, 1.5E^{-4} in the leafy, fruit, and root vegetables, respectively) indicated moderate carcinogenic health risks, while the TCR value for Cd (6.1E $^{-3}$, 3.9E $^{-3}$, and 7.2E $^{-3}$ in the leafy, fruit, and root vegetables, repectively) represented high cancer risks. Therefore, the TCR values of Pb and Cd in the studied samples were associated with moderate-to-high carcinogenic health risks to the local population.

In order to identify the possible sources of heavy metal contamination in the samples, the concentrations of heavy metals in the soil were also examined. In addition, the concentration of each heavy metal in the soil samples was compared with the reference values proposed by Mahfuza et al. [23]. Figure 3 shows that the concentrations of Fe, Cu, Zn, Cd, and Pb were within the permissible limits, with the exception of Mn as the soil samples were observed to be slightly polluted by this element. On the other hand, the mean concentrations of the heavy metals in the studied soil samples were compared with similar studies in Bangladesh and other countries (Table 4). The results of the present study revealed that the mean concentrations of Fe, Cu, and Zn in the soil samples were lower compared to the other studies in this regard, with the exception of Mn, Cd, and Pb.

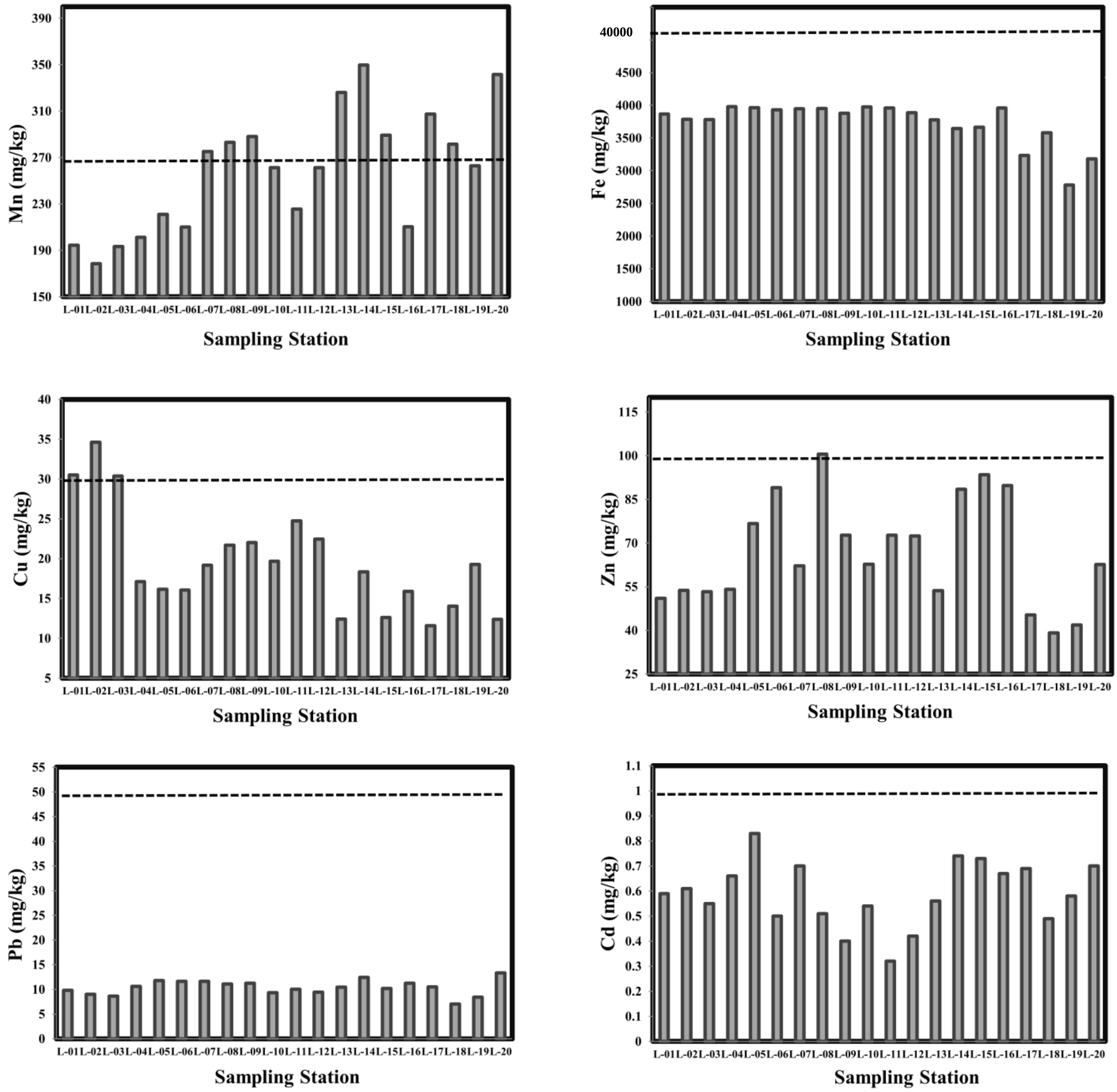

Figure 3: Comparison of heavy metal concentration in the soil samples with reference values [23]

Table 4: Comparison of average heavy metal concentrations (mg/kg) in soil with other studies [6]

Study Area	Mn	Fe	Cu	Zn	Cd	Pb
Entire Bangladesh	669.56	37247.15	54.29	202.81	1.26	9.4
Jashore, Bangladesh	199.38	3773.29	11.85	49.58	0.68	12.61
Iswardi, Bangladesh	283.50	15684.70	21.43	123.283	0.538	68.84
Chittagong, Bangladesh	160.79	--	32.63	139.30	2.43	7.33
Mymensingh, Bangladesh	182.33	24683.33	49.10	123.19	--	59.39
Bogra, Bangladesh	--	--	131.87	28.46	6.95	9.6
Gazipur, Bangladesh	--	--	36.18	176.66	0.2	75
Dhaka, Bangladesh	--	--	75.04	103.34	0.52	3.84
Dhaka, Bangladesh	--	21216	37.57	--	0.45	50.32
Dhaka, Bangladesh	1715.80	--	39.14	115.43	11.42	49.71
Manila, Philippines	1999.00	--	98.70	440.00	0.57	213.6
Bangkok, Thailand	340.00	--	41.70	118.00	0.29	47.8
Palermo, Italy	519.00	--	63.00	138.00	0.68	202
Sialkot, Pakistan	17991.62	--	26.85	94.2	36.8	121.4
Uttar Pradesh, India	--	--	42.90	159.90	--	38.3
Fuyang, China	--	--	40.77	159.85	0.37	40.59
Mongla, Bangladesh	258.08	3736.90	19.55	66.76	0.59	10.40

Source: Ara et al. (2018)

4. Conclusion

According to the results, the concentrations of heavy metals in the soil samples were below the safe limits. However, the concentrations of Fe, Cd, and Pb in the vegetable samples were above the permissible limits recognized by the FAO/WHO. Anthropogenic sources, such as the excessive use of wastewater, fertilizers, and pesticides in agricultural fields, atmospheric depositions from vehicle emissions, metallic oxide, and various particulate matters emitted from industries, could also be among the possible sources of contamination.

Various health risk indices (EDI, THQ, HI, and TCR) were evaluated in the present study, indicating moderate-to-high health risks for humans. Consumption of contaminated vegetables is the most significant concern in terms of the associated carcinogenic and non-carcinogenic health effects. The findings of the current research could be used as an important reference for further investigations on water, fertilizers, and pesticides as other sources of contamination. Therefore, effective measures should be taken to raise awareness in this regard and properly control heavy metal contamination in different areas in Bangladesh.

Authors' Contributions

M.H.A. and P.K.D., conceptualization and study design; M.A.R.K, methodology and field work; M.N.U., data analysis; P.K.D., drafting of the manuscript; and M.H.A., visualization, supervision, and fund acquisition.

Conflict of Interest

The authors declare no conflict of interest

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