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Research Article

Evaluation of Heavy Metals in Vegetables from Contaminated Agricultural Soils of Madhyapur Thimi, Bhaktapur District, Nepal and their Potential Health Risk Assessment

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Abstract

The present study aimed to determine Cd, Cr, Cu, Pb, and Zn concentrations using flame atomic absorption spectrophotometer (FAAS) in five vegetables *viz*., Coriander (*Coriandrum sativum*), Mustard (*Brassica campestris*), Radish (*Raphanus sativus*), Spinach (*Spinacea oleracea*) and Chinese spinach (*Amaranthus dubius*), and their growing soils in three agricultural sites (Manohara, Bode, and Nagadesh) of Madhyapur Thimi, Bhaktapur district and to assess health risks using USEPA deterministic approaches. The average concentrations of HMs in soils were 0.85, 30.65, 40.06, 47.42, and 129.55 mg/kg for Cd, Cr, Cu, Pb, and Zn respectively, exceeding the normal soil quality standards except Cr. Similarly, the average concentrations of HMs in vegetables were 0.42, 6.63, 22.33, 1.34, and 77.16 mg/kg for Cd, Cr, Cu, Pb, and Zn respectively exceeding joint FAO/WHO standards except for Cu. The I-geo values revealed a class of unpolluted to moderately polluted levels for the agricultural soils indicating the 1st degree of soil pollution. Among the vegetables, Chinese spinach measured considerably high transfer factor (TF) for Cd (0.79), Cr (0.34), Cu (0.76), Pb (0.04), and Zn (0.89) indicating health concerns to the consumers. The hazard index (HI) for these HMs was found less than the acceptable limit (1.0) indicating no non-carcinogenic risk to adults through vegetable consumption. However, the lifetime carcinogenic risk (LCR) parameter indicated low to high cancer risk for Cd, Cr, and Pb. Among the vegetables, Chinese spinach estimated the highest LCR values for the HMs suggesting regular monitoring of HMs in soil and vegetable on account of their toxic effects.

Keywords: Agricultural soils; Bhaktapur district; Cancer risk; Heavy metals; Vegetables

Introduction

Vegetables are fresh edible portions of certain herbaceous plants having roots, stems, leaves, flowers, fruit, or seeds. There are different categories of vegetables such as leafy green, root, cruciferous, stem, marrow, and allium. They constitute an important part of the human diet since they are good sources of carbohydrates, proteins, minerals, and principally vitamins A and C. Nearly all vegetables are rich in dietary fiber, metabolites, and antioxidants (Thompson and Kelly, 1990). People all over the world have more concern over fresh vegetable intake because of the huge benefits of safe consumption. A diet rich in vegetables and fruits can lower blood pressure, reduce the risk of heart disease and stroke, prevent some types of cancer, lower the risk of eye and digestive problems, and have a positive effect upon blood sugar. They also play a significant role to reduce diabetics, cardiovascular and other aged related diseases (Prakash *et. al.,* 2012; Wong *et. al.*, 2003). Moreover, vegetables also function as buffering agents for acid substances that are obtained during the digestion process and can keep appetite in check (Thompson & Kelly, 1990).

Naturally occurring metals having an elemental density greater than 5 g cm^{-3} are called heavy metals (Gadd and Griffiths, 1977). They are non-biodegradable and persistent environmental contaminants and hence readily accumulate in soil and vegetable to toxic levels. The rapid growth of industrialization and urbanization release significant levels of heavy metals into the environment (Wong *et. al.*, 2003). Soils get contaminated with heavy metals through several anthropogenic activities such as irrigation using untreated wastewater, disposal of high metal wastes, leaded gasoline and paints, fertilizers, pesticides, sewage sludge, organic manure, disposal of urban and industrial wastes, spillage of petrochemicals, fossil fuels combustion and atmospheric deposition (Khan *et al.*, 2008; Zhang, 2010). Soils are the major sink for heavy metals released into the environment. Soil contaminated with heavy metals may pose risks and hazards to humans through ingestion, inhalation, and dermal contact pathways (McLaughlin *et al.*, 2000). They also enter the body through the food chain (soil-plant-animal-human) and by drinking of contaminated groundwater (Ling *et al.*, 2007). Some studies have shown that the toxicity and mobility of heavy metals in soil depend on their specific forms or binding condition (Kashem *et al.*, 2007). Therefore, the geochemical fractionation of heavy metals in soil is necessary to know the fate and behavior of metals in soil. Furthermore, consumption of heavy metals-contaminated vegetables can seriously deplete some essential nutrients in the body causing a decrease in immunological defenses, intrauterine growth retardation, impaired psychosocial behavior, disabilities associated with malnutrition, and a high prevalence of upper gastrointestinal cancer (Arora *et al.*, 2008).

Soil to plant transfer of heavy metals is the major pathway of human exposure to soil contamination. Heavy metals such as As, Cd, Cr, Cu and Pb have been considered the most toxic elements in the environment and therefore, included in the US Environment Protection Agency (USEPA) list of priority pollutants (Cameron, 1992; Lei *et al.*, 2010). However, the most common heavy metals found at contaminated sites are Pb, Cr, As, Zn, Cd, Cu, and Hg (USEPA, 1996). These metals are important since they are capable of decreasing crop production due to the risk of bioaccumulation and biomagnification in the food chain. The uptake and bioaccumulation of heavy metals in vegetables are influenced by many factors such as climate, atmosphere depositions, the concentrations of heavy metals in soil, the nature of the soil, and the degree of maturity of the plants at harvest (Scott *et al.*, 1996; Voutsa *et al.*, 1996). Besides, the uptake of heavy metals by plants also depends on a number of physical processes such as root intrusion, water, and ion fluxes and their relationship to the kinetics of metal solubilization in soils, biological parameters, including the kinetics of membrane transport, ion interactions, and metabolic fate of absorbed ions (Cataldo and Wildung, 1978).

There are several studies on associated health risk due to consumption of vegetables contaminated with heavy metals. Islam *et al.* (2018) reviewed studies on heavy metals accumulation in soil irrigated with polluted water and human health risk from vegetable consumption by inhabitants of the cites of Bangladesh. Hussain and Qureshi (2020) evaluated the significant impact of heavy metals on human health due to consumption of leafy, root, and fruit vegetables irrigated with treated wastewater at Dubai, UAE. Ashraf *et al.* (2021) assessed heavy metals in water, soil, vegetables from District Kasur, Pakistan and also evaluated their associated health risks *via* consumption of vegetables. Atamaleki *et al.* (2021) reviewed concentrations of potentially harmful elements (PHEs) in the edible part of lettuce and coriander vegetables irrigated by wastewater and also evaluated carcinogenic risk (CR) and noncarcinogenic risk (non-CR) for consumers. Bhaktapur district is well known for vegetable production and fulfilling dietary needs of the inhabitants of Kathmandu valley. As a matter of fact, it is obvious to raise concern on the consumption of safe and nutritious vegetables on account of the importance of public health. However, the survey of literature revealed that there are very limited studies on health risk assessment of heavy metals in vegetables from contaminated agricultural soils of Nepal in general and Kathmandu valley in particular. Therefore, the objective of this study was to evaluate Cd, Cr, Cu, Pb, and Zn concentrations in soils and vegetables from contaminated agricultural soils of Madhyapur Thimi, Bhaktapur district and to assess non-carcinogenic and carcinogenic health risks. The findings of the study may be useful in bringing public awareness to the soil environment and public health issues in the related area of interest.

Materials and Methods

Study Area and Selection of Sampling Sites

Bhaktapur (Fig. 1), located in the eastern part of Kathmandu valley, is the smallest district of Nepal. The district covers the region between 27°36′ - 27°44′ northern latitude and

85°21′ - 85°32′ eastern longitude along with 16 km of the east-west length. It is located at an altitude ranging from 1,331 to 2,191 meters above the sea level. It has an area of 119 km² with a population of 4,30,408 and a population density of 3617/km^2 according to the National Census 2021 AD.

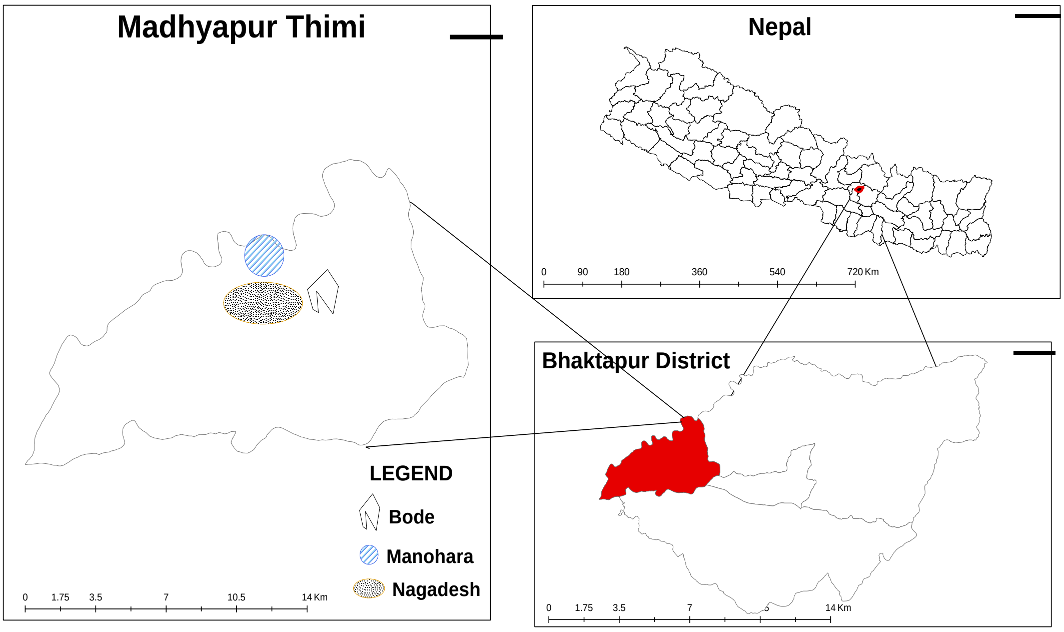

Figure 1. Map of Bhaktaur district, Nepal showing study area and sampling sites

Bhaktapur has 11,900 hectares of land of which 11,106 hectors of land is suitable for agriculture. The pocket areas for vegetable production in the district are Madhyapur Thimi, Bageshwori, Jhaukhel, Duwakot, Sipadol and Dadhikot. Among them, Madhyapur Thimi is well known municipality for commercial vegetable production fulfilling the vegetable needs of the valley. During field survey in (October-November) 2021, only three agricultural sites *viz.*, Manohara, Bode, and Nagadesh of the municipality were found to be cultivated with five vegetable types while others were mostly paddy fields. The five vegetable types cultivated at the study sites were Coriander (*Coriandrum sativum*), Mustard (*Brassica campestris*), Radish (*Raphanus sativus*), Spinach (*Spinacea oleracea*) and Chinese spinach (*Amaranthus dubius*). All three agricultural sites and five test vegetables were, therefore selected for the present investigation.

Collection of Soil and Vegetable Samples

From each agricultural site, about 100 g of soil samples were collected by chopping the surface soil to a depth of 15 cm manually with the help of a metallic core cutter. Five replicates of soil samples from each vegetable farm were collected separately at an equal distance and direction from the center of the first collection. All the samples collected in separate polythene bags with zip locks were properly labeled and immediately transported to the laboratory. The samples were air dried at room temperature and sieved through a 2 mm size metal-free sieve to remove debris, stones, and pebbles. For the purpose of metal analysis, about 50 g of each sample was oven dried at 105 ^{0}C for several hours until free from moisture. A commercial grinder was used to grind them into a fine powder and packed in airtight clean and well-labeled polythene bags. They were stored at -4^{o}C until further chemical analysis.

Vegetable samples, fully matured and ready for harvesting, were collected from the same vegetable farms where the soil samples were collected. Each vegetable type in five replicates from cluster of each vegetable farm was randomly collected. The collected vegetable samples were washed with distilled water to remove soil adhered and transferred into well-labeled zip lock polythene bags. All the collected samples were transported to the laboratory. The edible parts of the vegetables were chopped into small pieces and then oven dried at 70–80 °C for several hours till constant weight (Bi *et al.*, 2018). The samples were ground to a fine powder using a commercial grinder and packed in airtight clean and well-labeled polythene bags. They were stored at -4^{o}C until chemical analysis.

Analytical Reagents and Chemicals

All the standard solutions (1000 ppm) for Cd, Cr, Cu, Pb and Zn were certified and purchased from Merck, Germany. These solutions were diluted carefully to the required concentrations with doubly-distilled water. All apparatus including the glassware and plastic vessels were treated with dilute (1:1) nitric acid for 24 h and then rinsed with distilled water before use. The acids, HCl, H_2SO_4, HNO_3, and $HClO_4$ (E. Merck, Germany) were of analytical grade and used without further purification. Doubly distilled water was used throughout the experiment.

Sample Preparation

For metal analysis in soils, 1.0 g (dry weight) of each sample was treated with an acid mixture of 20 mL (1:1) HNO_3 and 5 mL 37% HCl in a clean and acid-washed beaker (Kayastha, 2014). The sample was then digested over the hot plate at a low temperature. The digestion process was continued until the volume was reduced to 1-2 mL and more acid was added as per necessity to carry out complete leaching of metals from the sample. After complete digestion and sufficient cooling, the sample was filtered into a 25 mL volumetric flask. using filter paper (Whatman 42). The beaker was rinsed with distilled water again, transferring the filtrate into the same volumetric flask, and then the final volume was made with distilled water through homogeneous mixing.

For metal analysis in vegetables, 1.0 g of each sample was treated with 15 mL of 5:1:1 tri-acid mixture (70% HNO_3, 70% H_2SO_4, and 65% $HClO_4$) in an acid-washed beaker (Allen, 1986). The mixture was subjected to digestion until the solution became transparent. After cooling, the digested sample was filtered into a 25 mL volumetric flask using Whatman 42 filter paper and the final volume was made following the same procedure as described above.

Sample Analysis

The concentrations of Cd, Cr, Cu, Pb and Zn in the digested soil and vegetable samples were analyzed by Flame Atomic Absorption Spectrophotometer (nov AA 350, Analytikjena, Germany) using air-acetylene flame (Welz, 1985). Standard solutions were prepared in series using the reference metals and then standard calibration curves constructed at specific wavelengths for detecting the metals under investigation. The instrumental parameters were used as described by the manufacturer. Standard reference materials (NIST SRM 1648) were analyzed for the precision and analytical accuracy of the instrument. The recovery from the reference materials was 98.2, 97.5, 97.3, 98.5, and 98.0 % for Cd, Cr, Cu, Pb, and Zn respectively. In order to determine the precision of the analytical process, a few samples from the sampling sites were analyzed three times. The standard deviation for the pretested samples was calculated to be 2.3, 2.5, 2.0, 3.0, and 2.8 % for Cd, Cr, Cu, Pb, and Zn respectively, and can be considered satisfactory for analysis of test samples. The detection limits were 9, 5, 3, 9, and 3 µg/L for Cd, Cr, Cu, Pb, and Zn, respectively.

Contamination Assessment Using Geo-accumulation (I-geo) Index

Geo-accumulation index (I-geo) was used to assess the presence and intensity of anthropogenic deposition of HMs contaminant on surface soil (Barbieri, 2016). This index, originally defined by Müller (1969), was used to quantify the degree of soil pollution by normalizing one elemental concentration in the surface soil with respect to the background concentration of the same element (Eqn. 1).

$$Igeo = log2\left[\frac{Cs}{1.5\ Cb}\right] \qquad (Eqn. 1)$$

Where, *Cs* is the concentration of heavy metal in a soil sample, and *Cb* is the background metal concentration. Factor 1.5 is used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences. The background concentrations of HMs were adopted from Turekian and Wedepohl (1961) because the values were not available in the case of Nepal. The background concentrations for Cd, Cr, Cu, Pb, and Zn are 0.3, 90, 45, 20, and 95 mg/kg respectively. To indicate the degree of HMs contamination or soil pollution, Müller (1969) presented seven grades of classification based on the I-geo values (Table 1).

Table 1: Classification of I-geo index

I-geo value	**Degree of metal contamination or soil pollution**	**Classification of soil quality**
Igeo ≤ 0	0	Practically unpolluted
0 < Igeo ≤ 1	1	Unpolluted to moderately polluted
1 < Igeo ≤ 2	2	Moderately polluted
2 < Igeo ≤ 3	3	Moderately to strongly polluted
3 < Igeo ≤ 4	4	Strongly polluted
4 < Igeo ≤ 5	5	Strongly to extremely polluted
Igeo ≥ 5	6	Extremely polluted

Transfer Factor (TF) of Heavy Metals (HMs)

Transfer factor (TF) of HMs from soil to the edible parts of a vegetable is defined as the ratio of the metal concentration in the vegetable tissues to the metal concentration in soil (Khan *et al.*, 2010; Li *et al.*, 2012). The TF for each test vegetable was calculated using Eqn. 2.

$$TF = \frac{Cveg}{Csoil} \qquad (Eqn. 2)$$

Where, *Cveg* and *Csoil* represent metal concentration in the edible parts of a vegetable and in soil respectively.

Health Risk Assessment

To assess health risks (non-carcinogenic and carcinogenic) associated with the ingestion of heavy metals through vegetable consumption, the estimated daily intake (EDI) of heavy metals, target hazard quotient (THQ), hazard index (HI), and lifetime cancer risk (LCR) were calculated.

Estimated Daily Intake (EDI)

The estimated daily intake of each heavy metal was calculated using Eqn. 3 (Chary *et al.*, 2008).

$$EDI = \frac{Cmetal \times Dveg}{BW} \qquad (Eqn. 3)$$

Where, *EDI* is the estimated daily intake of each heavy metal from vegetable (mg/day/kg body weight); *Cmetal* is the metal concentration in vegetables (mg/kg), *Dveg* is the daily intake of vegetables (kg/person/day) and *BW* is the average body weight of a person (kg). The average daily consumption of 200 g of vegetables was assumed in this study. Similarly, the average body weight of an adult was considered 60 kg (Shakya & Khwaounjoo, 2013).

Non-carcinogenic Health Risk

The methodology for the estimation of non-carcinogenic risks was applied in accordance with the provision of USEPA Region III's Risk-based Concentration Table (USEPA, 2010).

Target Hazard Quotient (THQ): The non-carcinogenic risk for each heavy metal was assessed using target hazard quotient (THQ), which is the ratio of a single metal exposure level over a specified time period to a reference dose (R*f*D) for that metal derived from a similar exposure period. The Eqn. 4 was used for estimating THQ:

$$THQ = \frac{EFr \times ED \times FIR \times C}{RfD \times BW \times AT \times 1000} \qquad (Eqn. 4)$$

Where, THQ is the target hazard quotient; EFr is the exposure frequency (365 days/year); ED is the exposure duration (70 years); FIR is the vegetable ingestion rate (200 g/person/day); C is the metal concentration in vegetables (mg/kg); R*f*D is the oral reference dose (mg/kg/day); *BW* is the average body weight of a person (kg) and AT is the averaging time for non-carcinogens (365 days/year × ED). The oral reference doses are based on 1.0×10^{-3}, 3.0×10^{-3}, 4.0×10^{-2}, 3.5×10^{-3}, and 0.3 mg/kg/day for Cd, Cr, Cu, Pb, and Zn, respectively (USEPA, 2010).

Hazard Index (HI): In order to assess the overall potential for non-carcinogenic effects from more than one heavy metal, a hazard index (HI) was used. Since different pollutants can cause similar adverse health effects, HI is calculated as the sum of hazard quotients (HQs). The index is based on the Guidelines for Health Risk assessment of Chemical Mixtures of US Environmental Protection Agency (USEPA, 1989) and calculated using Eqn. 5 as:

$$HI = \Sigma THQ\,(THQ1 + THQ2 + THQ3 \ldots\ldots\ldots + THQn) \qquad (Eqn. 5)$$

In the event of HI ≤ 1, adverse health effects would be unlikely to occur. However, potential non-carcinogenic effects would occur when HI > 1 as this indicates a significant non-carcinogenic risk posed to human health (Staff, 2001).

Lifetime Cancer Risk (LCR)

Incremental lifetime cancer risk (LCR) is the lifetime probability of an individual developing any type of cancer due to carcinogenic daily exposure to a contaminant over a lifetime. Eqn. 6 was used for estimating lifetime cancer risk (USEPA, 1989):

$$LCR = \frac{EFr \times ED \times FIR \times C \times CSFo}{BW \times AT \times 1000} \qquad (Eqn. 6)$$

Where, LCR represents the lifetime cancer risk; AT is the averaging time for carcinogens (365 days/year × ED); and CSFo is the oral carcinogenic slope factor from the Integrated Risk Information System US Environmental Protection Agency (USEPA, 2010) database. The oral carcinogenic slope factors for Cd, Cr, and Pb are 6.3, 0.5, and 8.5×10^{-3} $(mg/kg/day)^{-1}$ respectively. The slope factors for Cu and Zn are unavailable since these elements are less likely to cause carcinogenic risk. According to NYSDOH (2007), the CR categories are described as follows: CR ≤ 10^{-6} = Low, 10^{-5} to 10^{-3} = moderate, 10^{-3} to 10^{-1} = high and ≥ 10^{-1} = very high. Element for which the risk factor falls below 10^{-6} may be eliminated from further consideration as a chemical of concern.

Statistical Analysis

IBM-PC computer was used for all data processing and statistical analyses in this study. Descriptive statistics such as frequency, percentage, mean and standard deviation were used wherever applicable. Correlation analyses of heavy metals between soils and vegetables were performed using Pearson's correlation coefficient along with the significance test.

Results and Discussion

Concentration of Heavy Metals (HMs) in Soils

The concentrations of five HMs (Cd, Cr, Cu, Pb and Zn) in agricultural soils of Manohara, Bode, and Nagadesh of Madhyapur Thimi, Bhaktapur are presented in Table 2.

Results showed wide ranges of variations in the HMs availability in soil samples across the selected agricultural sites of Madhyapur Thimi. The overall average concentrations of the metals in soil samples were found in the descending order of Zn > Pb > Cu > Cr > Cd in consistent with several other studies (Kayastha, 2014; Islam *et al.*, 2016; Ara *et al.*, 2018a; Ashraf *et al.*, 2021). Accordingly, the average concentrations were 0.85, 30.65, 40.06, 47.42, and 129.55 mg/ kg for Cd, Cr, Cu, Pb, and Zn respectively.

Table 2: Concentrations of heavy metals (mg/kg) in agricultural soils (mean ± SD, n=5, dw) of Madhyapur Thimi, Bhaktapur.

Location	Heavy metals				
	Cd	Cr	Cu	Pb	Zn
Manohara	0.93 ± 0.18	35.84 ± 9.68	46.91 ± 10.15	52.67 ± 7.68	152.90 ± 7.47
Bode	0.90 ± 0.12	25.99 ± 5.57	35.18 ± 5.66	43.04 ± 10.80	131.45 ± 6.71
Nagadesh	0.71 ± 0.08	30.13 ± 5.39	38.09 ± 7.23	46.56 ± 10.53	104.29 ± 11.69
Mean of all sites	0.85	30.65	40.06	47.42	129.55
*Normal soil value	0.35	70	30	35	90
** Critical upper soil value	8	100	125	400	400

*Bowen (1979); **Kataba-Pendias and Pendias (1992)

These concentration levels were found to exceed the normal soil value (Bowen, 1979) except for Cr; however, they were found considerably below the critical upper soil value (Kataba-Pendias & Pendias, 1992). The selected sites also showed a range of concentrations varying from 0.71 –0.93, 25.99 – 35.84, 35.18 – 46.91, 43.04 – 52.67 and 104.29 – 152.90 mg/ kg for Cd, Cr, Cu, Pb, and Zn respectively. Besides, all three agricultural sites demonstrated average concentrations in the descending order of Zn > Pb > Cu > Cr > Cd. Among the study sites, Manohara recorded comparatively high concentrations of Cd (0.93 mg/kg), Cr (35.84 mg/kg), Cu (46.91 mg/kg), Pb (52.67 mg/kg) and Zn (152.90 mg/kg) in soil samples. In this agricultural location, soil contamination may be due to the application of agrochemicals in soils including diammonium phosphate (DAP) and urea fertilizers, pesticides, sludge, and manure (Wong *et al.*, 2002; Kayastha, 2014). Besides, the downstream river erosion, wastewater or river irrigation, wind transportation, and brick kiln may also affect the metal levels in soils (Khan *et al.*, 2013a).

Concentrations of Heavy Metals (HMs) in Edible Parts of Vegetables

The average concentrations of Cd, Cr, Cu, Pb, and Zn in edible parts of the test vegetables at different agricultural sites of Madhyapur Thimi, Bhaktapur are listed in Table 3.

The concentrations of the selected HMs were found to vary among the vegetable types and sampling locations. The variation in metal concentrations among the vegetable species may be attributed to differential absorption capacity and affinity of vegetables for different HMs (Singh *et al.*, 2010). Results revealed that the overall average concentrations of HMs in all test vegetable types followed the decreasing order of Zn > Cu > Cr > Pb > Cd. Accordingly, the average concentrations were 0.42, 6.63, 22.33, 1.34, and 77.16 mg/kg for Cd, Cr, Cu, Pb, and Zn respectively. The selected vegetable types also showed the range of metal concentrations varying from 0.12 – 0.67, 2.52 – 10.38, 11.73 – 30.41, 1.02 – 1.88, and 34.67 – 112.85 mg/ kg for Cd, Cr, Cu, Pb, and Zn respectively. Evidently, all the HMs except Cu were found to cross the maximum allowable level as per FAO/WHO (2011) guidelines. Similarly, all vegetable types showed their average concentrations (average of 3 sites) following the same descending order of Zn > Cu > Cr > Pb > Cd, irrespective of their sampling locations. The concentration of these metals except Cu exceeded the maximum allowable level for vegetables (Table 3). The average concentration of Cd in vegetables from all three agricultural sites followed the decreasing order of Chinese spinach > spinach > mustard > coriander > radish. Accordingly, Cd concentration was found to be comparatively high in Chinese spinach (0.67 mg/kg) and low in radish (0.31 mg/kg). The results of the present study are in agreement with several studies (Islam *et al.*, 2016; Ara *et al.*, 2018b; Ashraf *et al.*, 2021). It was found that different vegetable types demonstrated different metal accumulation capacities within the same environment. This may be attributed to different ligands associated with the binding sites of vegetables in addition to pH, lime, organic matter, and phosphate as factors that influence metal uptake (Streit & Stumm, 1993). Besides, Cd bioaccumulation by all five vegetable types except mustard was found comparatively high at Manohara. This may be attributed to the injudicious use of fertilizers, manure and sewage, and contaminated river water for irrigation which can remarkably increase the Cd uptake by plant tissues (Alloway & Jackson, 1991).

Table 3: Concentrations of heavy metals (mg/kg) in vegetables (mean ± SD, n=5, fw) cultivated at different agricultural sites of Madhyapur Thimi, Bhaktapur.

Vegetables	Location	Heavy metals				
		Cd	Cr	Cu	Pb	Zn
Coriander	Manohara	0.33 ± 0.05	5.39 ± 1.33	20.16 ± 2.10	0.97 ± 0.03	54.44 ± 7.55
	Bode	0.31 ± 0.04	5.03 ± 0.91	18.77 ± 2.04	1.33 ± 0.51	65.22 ± 5.96
	Nagadesh	0.30 ± 0.07	5.21 ± 0.68	18.84 ± 2.54	0.98 ± 0.13	54.91 ± 7.40
	Mean value of 3 sites	0.31	5.21	19.26	1.09	58.19
Mustard	Manohara	0.41 ± 0.04	6.82 ± 2.53	25.95 ± 5.41	1.24 ± 0.25	80.79 ± 5.23
	Bode	0.46 ± 0.06	5.72 ± 1.24	20.95 ± 3.52	1.43 ± 0.65	82.19 ± 5.17
	Nagadesh	0.45 ± 0.06	6.68 ± 1.73	21.23 ± 5.03	1.09 ± 0.09	70.06 ± 3.48
	Mean value of 3 sites	0.44	6.41	22.71	1.25	77.68
Radish	Manohara	0.15 ± 0.03	2.48 ± 0.76	10.94 ± 2.80	0.84 ± 0.15	39.35 ± 3.82
	Bode	0.12 ± 0.03	2.16 ± 0.69	11.15 ± 1.40	1.21 ± 0.50	36.13 ± 5.17
	Nagadesh	0.10 ± 0.02	2.92 ± 0.97	13.11 ± 1.78	1.02 ± 0.23	28.54 ± 6.65
	Mean value of 3 sites	0.12	2.52	11.73	1.02	34.67
Spinach	Manohara	0.60 ± 0.03	9.23 ± 0.76	32.68 ± 2.80	1.43 ± 0.15	117.02 ± 3.82
	Bode	0.55 ± 0.06	8.92 ± 1.74	27.00 ± 1.95	2.32 ± 0.76	109.18 ± 9.11
	Nagadesh	0.54 ± 0.07	7.67 ± 1.20	23.00 ± 4.62	1.20 ± 0.26	81.03 ± 3.11
	Mean value of 3 sites	0.56	8.61	27.56	1.65	102.41
Chinese spinach	Manohara	0.78 ± 0.07	10.95 ± 0.21	40.04 ± 1.61	2.13 ± 0.28	130.45 ± 14.18
	Bode	0.59 ± 0.14	10.55 ± 1.19	25.71 ± 3.35	2.24 ± 0.69	114.43 ± 6.61
	Nagadesh	0.65 ± 0.07	9.63 ± 2.10	25.49 ± 6.18	1.26 ± 0.36	93.67 ± 10.82
	Mean value of 3 sites	0.67	10.38	30.41	1.88	112.85
Mean of overall sites		0.42	6.63	22.33	1.34	77.16
*Max. allowable level		0.05	2.3	40.0	0.1	20.0

*FAO and WHO (2011)

Cadmium is a trace element that is ubiquitous in soil. It is the most toxic heavy metal due to its high mobility and non-essential for living organisms (Nagajyoti *et al.*, 2010). Hence, its' bioaccumulation can lead to health disorders even at low doses. Moreover, Cd is reportedly a carcinogenic and endocrine disrupter and can cause lung damage and bone fragility (He *et al.*, 2015).

The average concentrations of Cr from all the three agricultural sites were found in the descending order of

Chinese spinach (10.38 mg/kg) > spinach (8.61 mg/kg) > mustard (6.41 mg/kg) > coriander (5.21 mg/kg) > radish (2.52 mg/kg). Among the HMs, Cr accumulation in the test vegetables was comparatively higher than those of Cd and Pb but lower than Cu and Zn (Table 3). Among the study sites, higher Cr accumulation was associated with the edible portions of coriander (5.39 mg/kg), mustard (6.82 mg/kg), spinach (9.23 mg/kg), and Chinese spinach (10.95 mg/kg) at Manohara except for radish (2.92 mg/kg) at Nagadesh. A study conducted by Rahman e*t al.* (2013) also showed a range of Cr accumulation in vegetables nearly close to the present study for leafy and non-leafy vegetables. The main sources of Cr contamination may be due to the repeated use of untreated or poorly treated wastewater from industrial establishments and the application of chemical fertilizers and pesticides (Islam *et al.*, 2009; Bhuiyan *et al.*, 2011). Chromium (III) is required in trace mount for humans but Cr (VI) is often carcinogenic and also causes nephritis and ulceration (Onakpa *et al.,* 2018).

In the present study, the average concentrations of Cu were 19.26, 22.71, 11.73, 27.56, and 30.41 mg/kg for coriander, mustard, radish, spinach, and Chinese spinach respectively. Results also showed higher Cu concentration in edible portions of coriander (20.16 mg/kg), mustard (25.95 mg/kg), spinach (32.68 mg/kg), and Chinese spinach (40.04 mg/kg) grown at Manohara agricultural site except for radish at Nagadesh site. Kayastha (2014) also presented similar results in different vegetable types in consistent with the present study. Ara *et al.* (2018a) also reported higher Cu in leafy vegetables as compared to non-leafy vegetables which could be due to the richness of chlorophyll. Copper is a trace element essential for human health. Upon exceeding its safe limit, it can cause brain damage, chronic anemia, kidney damage, intestine irritation, liver cirrhosis, spontaneous abortions, and gestational diabetes (Henriques *et al.*, 2017).

Results showed that the average concentrations of Pb were found in the decreasing order of Chinese spinach (1.88 mg/kg) > spinach (1.66 mg/kg) > mustard (1.25 mg/kg) > coriander (1.09 mg/kg) > radish (1.02 mg/kg). The results are in consistent with Ara *et al.* (2018b) who also reported significantly less Pb accumulation with radish. Among the study areas, Bode observed a comparatively high accumulation of Pb in all five vegetable species. Accordingly, this agricultural site exhibited Pb accumulation of 1.33, 1.43, 1.21, 2.32, and 2.24 mg/kg for coriander, mustard, radish, spinach, and Chinese spinach respectively. Burning activities of industrial waste, coal in brick kilns, and dense traffic activities might cause the deposition of Pb on soils and vegetables (Islam *et al.*, 2016). Besides, a major pathway for Pb to enter the above-ground tissues of plants is through foliar deposition (Xu *et al.*, 2013). Notably, Pb accumulation in soils in the present study was high (Table 2) but uptake by vegetable tissues was found significantly low (Table 3) in consistent with the findings of Ara *et al.* (2018b). The plausible reason may be due to high organic matter and clay particles in soils that can bind metal cations and become unavailable to plants and organisms in the soil (Hodgson, 1963; Gadd & Griffths 1978; Bassuk, 1986). Lead is a non-essential element for living organisms and is therefore toxic even at low concentrations. The toxic effect of Pb is associated with low birth, weightlessness, premature birth, spontaneous abortions, as well as hypertension. Besides, it is also associated with the risk of cardiovascular and neurotoxic diseases (Grant *et al.*, 2013).

Hyperaccumulation of Zn in all test vegetables was also observed in the decreasing order of Chinese spinach (112.85 mg/kg) > spinach (102.41 mg/kg) > mustard (77.68 mg/kg) > coriander (58.19 mg/kg) > radish (34.67 mg/kg) like other metals and the concentrations exceeded the maximum permissible level (20.0 mg/kg). Among the study sites, Mahohara demonstrated comparatively high Zn uptake in radish (39.35 mg/kg), spinach (117.02 mg/kg) and Chinese spinach (130.45 mg/kg) whereas Bode showed high Zn in coriander (65.22 mg/kg) and mustard (82.19 mg/kg). The possible reason for Zn hyperaccumulation in vegetable tissues may be due to the easy transportation of the metal from the roots into the aerial parts owing to its small ionic size and greater affinity for plants (Sharma & Chhetri, 2005). Besides, zinc content in soil and vegetable could be due to the extensive use of chicken manure, zinc in fertilizers, and metal-based pesticides (Alloway & Jackson, 1991). Zinc was also reported to be high in many vegetable types grown and marketed in Kathmandu (Shakya & Khwaounjoo, 2013; Sharma & Chettri, 2005) in consistent with the findings of the present study. Similarly, Sharma *et al.* (2009) also found hyperaccumulation of Zn in vegetables collected from the market as well as production sites in Varanasi city, India. Zinc is a trace element essential for both plants and animals but exposure to excessive quantity for a long duration may lead to dizziness, fatigue, vomiting, renal damage, decreased Immune function etc., (Mishra *et al.*, 2019).

In the present study, metal association with edible parts of the leafy vegetables were found significantly higher than root-type vegetable (radish). The plausible explanations for the high association of metals with leafy vegetables are that leafy vegetables can absorb large particles of heavy metals through their pores and cuticles due to their large surface areas. In addition to transpiration phenomena, the large leaves of leafy vegetables make them sensitive recipients of dust and splashing rainwater, which play an essential role in the accumulation of heavy metals in plants (Khan *et al.*, 2013b; Gupta *et al.*, 2019). Besides, the uptake and bioaccumulation of heavy metals in vegetables are also influenced by many factors such as climate, atmosphere depositions, the concentrations of heavy metals in soil, the nature of soil, and the degree of maturity of the plants at harvest (Scoott *et al.*, 1996; Voutsa *et al.*, 1996).

Correlation Analysis

The correlation between different variables is frequently expressed by Pearson's correlation coefficient which indicates their potential sources (Puth *et al.*, 2014). Inter-relationships between the metal concentrations in soil and vegetable samples were investigated in terms of the correlation matrix (Table 4).

Table 4: Correlation matrix showing Pearson's correlation coefficient between the concentration of heavy metals in soil and edible part of vegetables.

Variables	Heavy metals				
	Cd	Cr	Cu	Pb	Zn
Coriander and soil	*0.950	*0.995	*0.980	0.790	0.029
Mustard and soil	0.458	*0.878	*0.980	0.410	*0.846
Radish and soil	*0.852	0.337	0.400	*0.990	*0.987
Spinach and soil	0.755	0.276	0.790	0.640	*0.969
Chinese spinach and soil	0.350	0.383	*0.970	0.054	*0.998

*Significant at P = 0.05

The correlation matrix shows positive correlation between the concentration of heavy metals in soil and edible parts of vegetables. Results revealed that the correlation of Cd (r = 0.950), Cr (r = 0.995) and Cu (r = 0.980) was found very significant between coriander and soil at p = 0.05 (Table 4). The correlation of Cr (r = 0.878), Cu (r = 0.980) and Zn (r = 0.846) was also found significantly strong between mustard and soil at p = 0.05. Similarly, radish and soil showed very significant correlation for Cd (r = 0.852), Pb (r = 0.990) and Zn (r = 0.987) at p = 0.05. Likewise, Zn also showed very strong correlation between spinach and soil (r = 0.969), Chinese spinach and soil (r = 0.998) and Cu between Chinese spinach and soil (r = 0.970) at p = 0.05. The positive correlations between the variables imply common contaminant sources (Lu *et al.*, 2009).

Contamination Level Based on Geo-accumulation Index (I-geo)

The I-geo values in agricultural soils of Madhyapur Thimi are presented in Table 5.

Table 5: Geo-accumulation index (I-geo)

Location	Heavy metals				
	Cd	Cr	Cu	Pb	Zn
Manohara	0.62	0.08	0.21	0.53	0.32
Bode	0.60	0.06	0.16	0.43	0.28
Nagadesh	0.48	0.07	0.17	0.47	0.22

Results revealed variable I-geo values for HMs at different agricultural sites. As might be evident from the index calculation, the I-geo values indicated the descending order of Cd > Pb > Zn > Cu > Cr in soils from all three agricultural sites under the present investigation. The results are also in good agreement with Wang *et al.* (2021) and Islam *et al.* (2020) who also reported higher I-geo values for Cd and Pb. Among the sites, Manohara showed the highest I-geo values for Cd (0.62), Pb (0.53), Zn (0.32), Cu (0.21), and Cr (0.08). The highest I-geo values so obtained for HMs in Manohara are most likely from the use of untreated wastewater for irrigation, vehicular and industrial emissions, application of inorganic fertilizer in the surrounding agricultural areas, agrochemicals, waste disposal, and airborne sources (Barbieri, 2016; Lu *et al.*, 2009). As for the classification of soil quality and degree of soil pollution based on the Igeo values (Table 6), Manohara, Bode, and Nagadesh demonstrated their I-geo class of $0 < \text{Igeo} \leq 1$ for all HMs indicating that their soil environment falls under the category "unpolluted to moderately polluted level". This further indicates that the selected agricultural sites suffered from the 1st degree of soil pollution in consistent with the results reported by Kayastha (2014).

Table 6: Classification of soil pollution based on geo-accumulation index at different agricultural sites of Madhyapur Thimi, Bhaktapur.

Igeo value	Location			Degree of soil pollution	Classification of soil quality
	Manohara	Bode	Nagadesh		
Igeo ≤ 0	-	-	-	0	Practically unpolluted
0 < Igeo ≤1	Cd, Cr,Cu, Pb, Zn	Cd, Cr, Cu, Pb, Zn	Cd, Cr, Cu, Pb, Zn	1	Unpolluted to moderately polluted
1 < Igeo ≤2	-	-	-	2	Moderately polluted
2 < Igeo ≤3	-	-	-	3	Moderately to strongly polluted
3 < Igeo ≤4	-	-	-	4	Strongly polluted
4 < Igeo ≤5	-	-	-	5	Strongly to extremely polluted
Igeo ≥ 5	-	-	-	6	Extremely polluted

Transfer Factor (TF)

The potential capability of vegetables to transfer metals from soil to their edible tissues can be evaluated by the transfer factor (TF). This is one of the key components controlling human exposure to metals through the food chain since they could have a direct impact on the health of consumers (Islam *et al.*, 2015). Table 7 shows the average TF values of heavy metals in the selected vegetables.

Table 7: Transfer factor (TF) of heavy metals from soil to the edible parts of a vegetable.

Vegetables	Transfer factor (TF)					Total
	Cd	Cr	Cu	Pb	Zn	
Coriander	0.37	0.17	0.48	0.03	0.45	1.50
Mustard	0.52	0.21	0.57	0.03	0.60	1.93
Radish	0.14	0.08	0.29	0.02	0.27	0.80
Spinach	0.66	0.28	0.69	0.04	0.80	2.47
Chinese spinach	0.79	0.34	0.76	0.04	0.89	2.82

Results revealed a large variation in TF values among the vegetable types and HMs. The average TF of heavy metals in coriander and radish were found in the descending order of Cu > Zn > Cd > Cr > Pb whereas mustard and spinach exhibited the descending order of Zn > Cu > Cd > Cr > Pb. Chinese spinach, however demonstrated the descending order of Zn > Cd > Cu > Cr > Pb. The results are in consistent with the studies of Islam *et al.* (2015) and Kharazi *et al.* (2021) who also demonstrated high values of TF for Zn and Cu in verities of vegetable species. Among the test vegetables, a higher value of TF (Table 7) was observed in coriander for Cu (0.48), mustard for Zn (0.60), spinach for Zn (0.80), and Chinese spinach for Zn (0.89). Radish, however, showed comparatively least TF values for all HMs. The high TF values of Zn and Cu reflect the high bioavailability of these elements in the vegetable species. Considering the total value of TF in vegetables, results revealed the descending order of Chinese spinach > spinach > mustard > coriander > radish. This indicates that vegetable crop like Chinese spinach is hyper-accumulative in nature. Apparently, leafy vegetables accumulate much higher concentrations of HMs than other vegetables due to their higher translocation and transpiration rates (Gupta *et al.*, 2019); the present result is also in agreement with the results reported by Zhang *et al.* (2014).

Health Risk Assessment

Estimated Daily Intake (EDI) of Heavy Metals (HMs)

An estimate of the dietary intake of HMs is presented here that examines the dietary exposure to HMs through the consumption of selected vegetables in the population's daily diet. The EDI values of the selected HMs for adults through the consumption of five vegetable types are shown in Table 8.

Table 8. Estimated daily intake (EDI) of heavy metals (mg/day/kg BW) for adults through consumption of contaminated vegetables.

Vegetables	Estimated daily intake (EDI)				
	Cd	Cr	Cu	Pb	Zn
Coriander	1.04×10^{-3}	1.74×10^{-2}	6.42×10^{-2}	3.64×10^{-3}	1.93×10^{-1}
Mustard	1.46×10^{-3}	2.13×10^{-2}	7.57×10^{-2}	4.17×10^{-3}	2.58×10^{-1}
Radish	4.07×10^{-4}	8.41×10^{-3}	3.91×10^{-2}	3.41×10^{-3}	1.15×10^{-1}
Spinach	1.87×10^{-3}	2.86×10^{-2}	9.18×10^{-2}	5.50×10^{-3}	3.41×10^{-1}
Chinese spinach	2.22×10^{-3}	3.46×10^{-2}	1.01×10^{-1}	6.26×10^{-3}	3.76×10^{-1}
Total	0.01	0.11	0.37	0.02	1.29
*Maximum Tolerable Daily Intake (MTDI)	0.03	0.20	30	0.21	60

*Joint FAO/WHO Expert Committee on Food Additives, (1999)

It was found that all vegetable types demonstrated EDI values in the descending order of Zn > Cu > Cr > Pb > Cd. The total daily intake of Cd, Cr, Cu, Pb, and Zn were 0.01, 0.11, 0.37, 0.02, and 1.29 mg/day, respectively. These values were found considerably low than the maximum tolerable daily intake (MTDI) recommended by Joint FAO/WHO (1999), indicating that these vegetables might pose a low risk to the consumers. The results of the present study are in agreement with Islam *et al.* (2016) who also disclosed the same order of HMs based on total EDI vales; however, their total EDI exceeded MTDI values in contrast to the present study. Similarly, Ara *et al.* (2018a) and Nassar *et al.* (2018) also obtained the same EDI order of Zn > Cu > Pb > Cd for vegetables. Furthermore, the EDI values for vegetables also showed the descending order of Chinese spinach > spinach > mustard > coriander > radish. Accordingly, Chinese spinach showed maximum EDI value of 3.76×10^{-1} mg/day for Zn, 1.01×10^{-1} mg/kg for Cu, 3.46×10^{-2} mg/kg for Cr, 6.26×10^{-3} mg/kg for Pb, and 2.22×10^{-3} mg/kg for Cd. Similar to the present study, Islam *et al.* (2016) also found EDI values of HMs in spinach in the order of Zn > Cu > Pb > Cd.

Non-carcinogenic and Carcinogenic Health Risk

The estimated THQs and HI for non-carcinogenic risk for adults through the consumption of vegetables are presented in Table 9.

Table 9. Non-carcinogenic risk of heavy metals for adults through consumption of contaminated vegetables.

Vegetables	Target hazard quotient (THQ) for HMs					Hazard index (HI)
	Cd	Cr	Cu	Pb	Zn	
Coriander	1.03×10^{-3}	5.71×10^{-3}	1.58×10^{-3}	1.03×10^{-3}	6.38×10^{-4}	1.00×10^{-2}
Mustard	1.45×10^{-3}	7.02×10^{-3}	1.87×10^{-3}	1.18×10^{-3}	8.51×10^{-4}	1.24×10^{-2}
Radish	4.01×10^{-4}	2.76×10^{-3}	9.64×10^{-4}	9.61×10^{-4}	3.80×10^{-4}	5.47×10^{-3}
Spinach	1.85×10^{-3}	9.43×10^{-3}	2.27×10^{-3}	1.55×10^{-3}	1.12×10^{-3}	1.62×10^{-2}
Chinese spinach	2.21×10^{-3}	1.14×10^{-2}	2.50×10^{-3}	1.76×10^{-3}	1.24×10^{-3}	1.91×10^{-2}

Results revealed that the THQ value for individual metal was found in the descending order of Cr > Cu > Cd > Pb > Zn for coriander, mustard, spinach and Chinese spinach except for radish. Similarly, the THQ values for vegetables were found in the descending order of Chinese spinach > spinach > mustard >coriander > radish for all HMs. Among the selected HMs, Cr showed the highest THQ values for all the vegetable types: Chinese spinach (1.14×10^{-2}), spinach (9.43×10^{-3}), mustard (7.02×10^{-3}), coriander (5.71×10^{-3}), and radish (2.76×10^{-3}). Among the vegetable types, Chinese spinach showed the highest THQ values for Cr (1.14×10^{-2}), Cu (2.50×10^{-3}), Cd (2.21×10^{-3}), Pb (1.76×10^{-3}), and Zn (1.24×10^{-3}). Although HI values (Table 9) for vegetables were found in the descending order of Chinese spinach (1.91×10^{-2}) > spinach (1.62×10^{-2}) > mustard (1.24×10^{-2}) > coriander (1.00×10^{-2}) > radish (5.47×10^{-3}), none of the values exceeded the acceptable limit of 1.0. This indicates that exposure to HMs through consumption of the test vegetables does not pose non-carcinogenic risks to adults.

Generally, human beings upon exposure to more than one pollutant may suffer combined or interactive adverse effects (Li *et al.*, 2013). Prolonged exposure to a specific carcinogen may lead to cancer, and the risk increases depending on the contact time. The risk associated with the carcinogenic effects of the target metal is expressed as the excess probability of contracting cancer over a lifetime of 70 years. Lifetime carcinogenic risk (LCR) denotes not only an estimation of the expected cancers, but it also represents the possibility of developing carcinogenic risks in an individual (NYSDOH, 2007). In the present study, the LCR values estimated from intake of only Cd, Cr and Pb were calculated since these elements may promote both non-carcinogenic and carcinogenic effects depending on the exposure dose. The LCR values of these HMs are presented in Table 10.

Table 10. Lifetime carcinogenic risk (LCR) of heavy metals for adults through consumption of contaminated vegetables.

Vegetables	Lifetime carcinogenic risk (LCR)				
	Cd	Cr	Cu	Pb	Zn
Coriander	4.33×10^{-4}	6.00×10^{-4}	-	2.14×10^{-6}	-
Mustard	6.11×10^{-4}	7.37×10^{-4}	-	2.45×10^{-6}	-
Radish	1.70×10^{-4}	2.90×10^{-4}	-	2.00×10^{-6}	-
Spinach	7.82×10^{-4}	9.90×10^{-4}	-	3.32×10^{-6}	-
Chinese spinach	9.36×10^{-3}	1.19×10^{-3}	-	3.67×10^{-6}	-

The LCR values of Pb for Chinese spinach (3.67×10^{-6}), spinach (3.32×10^{-6}), mustard (2.45×10^{-6}), coriander (2.14×10^{-6}), and radish (2.00×10^{-6}) indicated that these vegetables posed low cancer risk to the exposed population. Similarly, it may be inferred from the LCR values for Cd and Cr that consumption of spinach (Cd: 7.82×10^{-4} and Cr: 9.90×10^{-4}), mustard (Cd: 6.11×10^{-4} and Cr: 7.33×10^{-4}), coriander (Cd: 4.33×10^{-4} and Cr: 6.00×10^{-4}), and radish (Cd: 1.70×10^{-4} and Cr: 2.90×10^{-4}) posed moderate cancer risk through their consumption. Moreover, the LCR values for Cd and Cr in Chinese spinach were 9.36×10^{-3} and 1.19×10^{-3} respectively. Hence, the vegetable contaminated with Cd and Cr might pose high cancer risk to the exposed population and these HMs could be marked as the most dominant carcinogen in this study area.

Conclusions

In the present study, concentrations of Cd, Cr, Cu, Pb, and Zn were evaluated in five vegetable types *viz*., coriander, mustard, radish, spinach, and Chinese spinach as well as soil samples from three agricultural sites (Manohara, Bode, and Nagadesh) of Madhyapur Thimi, Bhaktapur district and estimated possible non-carcinogenic and carcinogenic health risks through the vegetable's consumption using USEPA deterministic approaches. The overall mean concentrations of HMs in soils of all three agricultural sites followed the decreasing order of Zn > Pb > Cu > Cr > Cd. Except for Cr, all the selected HMs exceeded the normal soil quality standards, indicating risk to the surrounding soil environment. Among the agricultural sites, Manohara measured the highest concentrations of HMs in soil. Similarly, all vegetable types measured the concentrations of HMs in the decreasing order of Zn > Cu > Cr > Pb > Cd. The studied HMs except Cu crossed the maximum allowable level for vegetables as per FAO/WHO (2011) guidelines irrespective of the sampling locations. Among the vegetable types, Chinese spinach measured the highest accumulation of all five HMs. Besides, Zn accumulation was found considerably high in edible parts of all vegetable types. The I-geo values indicated a class of unpolluted to moderately polluted soil quality in all three agricultural sites of Madhyapur Thimi, and affected by the 1st degree of soil pollution indicating environmental concern to the local farmers. As for transfer factor (TF), Chinese spinach measured considerably high TF values for individuals as well as total HM indicating health concerns to the consumers. Regarding potential health risks due to HMs exposure, HI values less than unity indicated non-carcinogenic risk less likely to occur in adults. However, LCR values indicated that vegetables contaminated with

Cd, Cr, and Pb might exert low to high lifetime carcinogenic risk to adults. Moreover, Cd and Cr enriched Chinese spinach might pose a high lifetime carcinogenic risk since their LCR values exceeded 10^{-3} in the present investigation. The entry of Cd, Cr, and Pb in the food chain is, therefore a matter of health concern. The present study suggests further investigation on the identification of potential metal contamination sources so that appropriate remediation technologies could be applied for reducing the level of HMs in soils and vegetables thereafter.

Conflict of Interest

The authors declare that there is no conflict of interest in the publication of this paper.

Authors' Contribution

An equal contribution was made from all authors at every stage of research work, manuscript preparation, critical revision of the manuscript for important intellectual content, and final approval of the manuscript.

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