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Investigation of Heavy Metal Accumulation in Vegetables and Health Risk to Humans From Their Consumption

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Heavy metals contamination of soil and edible parts of vegetables is presently a challenging environmental issue worldwide. The present study determined the accumulated amount of cadmium (Cd), lead (Pb), nickel (Ni), cobalt (Co), zinc (Zn), copper (Cu), and manganese (Mn) in soil, coriander, onion, and tomato collected from agricultural fields of Jhansi city, India. The bio-concentration factor and non-carcinogenic health risks were also assessed to know the vegetables' accumulation potential of heavy metals from soil and possibility to have non-carcinogenic health risks via an intake of these vegetables. The samples were digested using di-acid solution prior to heavy metals analysis by atomic absorption spectrometric method. The average content of Cd, Pb, Ni, Co, Zn, Cu, and Mn were 2.02, 19.09, 21.56, 9.31, 35.34, 14.96, and 15.21 mg/kg dry weight (dw) in soil, 0.23, 2.12, 0.77, 0.47, 36.65, 5.92, and 21.65 mg/kg dw in coriander, 0.13, 0.66, 0.54, 0.32, 23.94, 6.25, and 20.15 mg/kg dw in onion, 0.14, 0.46, 0.89, 0.22, 16.77, 4.77, and 14.46 mg/kg dw in tomato, respectively. The bio-concentration factor revealed significant accumulation of Zn (1.04) and Mn in coriander (1.42), and in onion (1.32). The target hazard quotient and health risk index signaled that the population consuming these vegetables is risk-free. However, it is recommended that the concentration of heavy metals in the soil and crops of the study area and its related health risks be regularly monitored to avoid significant health risks in the future.

Keywords: heavy metals, hazard quotient, risk index, vegetables, accumulation

INTRODUCTION

Heavy metals and metalloids are the natural and structural part of the earth's crust with a density greater than 5 g/cm^3. Many of them are environmentally persistent and non-degradable contaminants. Initially, they are deposited on the soil surface, then absorbed by the apoplast of plant roots and further distributed and accumulated into their edible and non-edible parts, posing an imminent danger to the food chain (Ahmad et al., 2019; Alsafran et al., 2021). A very less amount of heavy metals can also be taken up by vegetables by atmospheric deposition (Prasad et al., 2021). Vegetables are major part of human platter as they have high amounts of fibers, minerals, vitamins, and antioxidants. Therefore, heavy metals contamination of vegetables cannot be ignored due to their significance in food quality assurance. Furthermore, the food chain pyramid is the track by which biologically toxic trace metals accumulated in humans and other animals (Gupta et al., 2019; Prasad et al., 2021).

Urban areas of developing countries like Pakistan (Alam et al., 2018), Bangladesh (Islam et al., 2016), Ethiopia (Gebeyehu and Bayissa, 2020), Ghana (Ametepey et al., 2018), South Africa (Fonge et al., 2021), and India (Yadav et al., 2015) reported to have high heavy metal levels due to rapid industrialization, wastewater irrigation, and other anthropogenic activities. Since seventy percent of the water is used for the agricultural sector (FAO, 2017), reuse of recycled wastewater for this purpose plays a significant role to achieve agriculture sustainability. Nevertheless, even recycled wastewater contains some pollutants including heavy metals and contaminates the soil and plants (Zwolak et al., 2019). In addition, petrochemical activities also increase soil contamination due to multiple oil spills incidences, waste disposals, chemical discharge, and gas flaring into the environment and may pose serious health issues to the ecosystem and human population (Sun et al., 2019). Furthermore, gasoline may also contribute to the increased concentrations of certain heavy metals such as Cd, Pb, Ni, Zn, and Cu in roadside soils and thus accumulate in vegetables (Kumar S. et al., 2019). Previous studies have shown that vegetables grown near industrial sites (Haque et al., 2021), mine site (Zhou et al., 2016), highways (Gupta et al., 2021a), and solid waste dump site (Njagi et al., 2017) contained more heavy metals than vegetables grown away from such sites. Hence, vegetables grown near industrial areas, mine sites, highways, and solid waste dump site may pose significant health risk for human beings and animals.

Nowadays, the public awareness of health risks is increasing the risk assessment associated with heavy metals contamination has become one of the hot topics worldwide. Prolonged consumption of high heavy metal levels through contaminated food may cause chronic heavy metals accumulation in humans' liver, kidney, and bones, resulting in kidney, cardiovascular, nervous, and bone diseases (Anwar et al., 2016). In addition, heavy metals may also create congenital disabilities and responsible for low birth weight of born babies (<2.5 Kg) and premature births (<37 weeks of completed gestation) (Taylor et al., 2015). Some heavy metals specifically Mn (Flora, 2014), Co (Simonsen et al., 2011), Cu (Wuana and Okieimen, 2011), Ni (Ihedioha et al., 2014), and Zn (Mohammadi et al., 2017) act as essential elements at certain concentrations in humans but they become noxious when exposed to higher doses. Whereas Cd (Khan et al., 2015), Pb (Jaishankar et al., 2014), As (Abdul et al., 2015), and hexavalent chromium [Cr(VI)] (Wang et al., 2017) may cause carcinogenic effects even in trace quantities. In addition, soil contamination with heavy metals is widely reported to cause health hazards (Gupta et al., 2021b). Further insight of meta-analysis into metal uptake by plants and its human health risk still needs to be investigated in India, China, and other countries. Hence, the current study aimed to evaluate the concentrations of Cd, Pb, Ni, Co, Zn, Cu, and Mn in agricultural soil and the edible parts of coriander, onion, and tomato. Furthermore, the non-carcinogenic risk of vegetable consumption on human health was also assessed to ensure the safety of the people in the vicinity of Jhansi city.

MATERIALS AND METHODS

Study Area

This study was conducted at the district of Jhansi, a known historic place in Uttar Pradesh State of India. The city has a historical background because the empress "Rani Lakhsmi Bai" ruled this city in the mid-19th century. This study area is situated between 25°07" to 25°57″ N and 78°10" to 79° 25″ E, in Jhansi city, which has an elevation above the mean sea level of 284 m. The average annual rainfall of this city is 885 mm and type of climate is sub-humid with hot and dry summer and cold winter (CGWB, 2017). Seven sampling sites were chosen for collection of samples on the basis of exposure to vehicular emission from the entire study area (**Figure 1**). A total of three national highways including NH-27 (from Porbandar to Silchar), NH-44 (from Srinagar to Kanyakumari), and NH-39 (from Jhansi to Ranchi) passed through the city. NH-27 adjoins the Jhansi to Kanpur which is a major financial and industrial center of North India and also called the 'Leather City of the World'. The vehicles coming from NH-44 and NH-39 pass through the selected sampling points to Kanpur.

Sampling of Soil and Vegetables

The soil and vegetable samples (coriander, onion, and tomato) were collected during spring and summer seasons from seven farmers' fields near the national highway NH-27, Jhansi city, as depicted in **Figure 1**. The vegetable samples were collected on the basis of availability in all farmers' fields at the same time. First of all, the soil samples were randomly collected in triplicate at a 0–15 cm depth using a spade from all selected sampling points. Then, the collected subsamples were mixed together to attain a 1 Kg of representative sample. Finally, soil samples were taken into labeled zippered polyethylene (PE) bags to prevent them from further contamination and immediately taken to the laboratory for further analysis. Similarly, the vegetable samples (edible parts) were also collected from same fields in triplicates and stored in pre-labeled zippered PE bags and taken to the laboratory for further processing. Details of vegetable samples are given in **Table 1**.

Soil and Vegetable Sample Processing and Experimental Procedure

The soil samples were dried in air at room temperature to attain a constant weight and ground using mortar and pestle to obtain fine-textured powder. However, in case of vegetables, the collected edible parts were first cut into small pieces using a pre-cleaned stainless steel knife and then dried in the laboratory oven at 75°C for 3 days. The dried vegetable samples were uniformly ground using mortar and pestle to fine-textured powder. The grounded fine-textured samples were stored in clean PE bags at room temperature for heavy metals and other

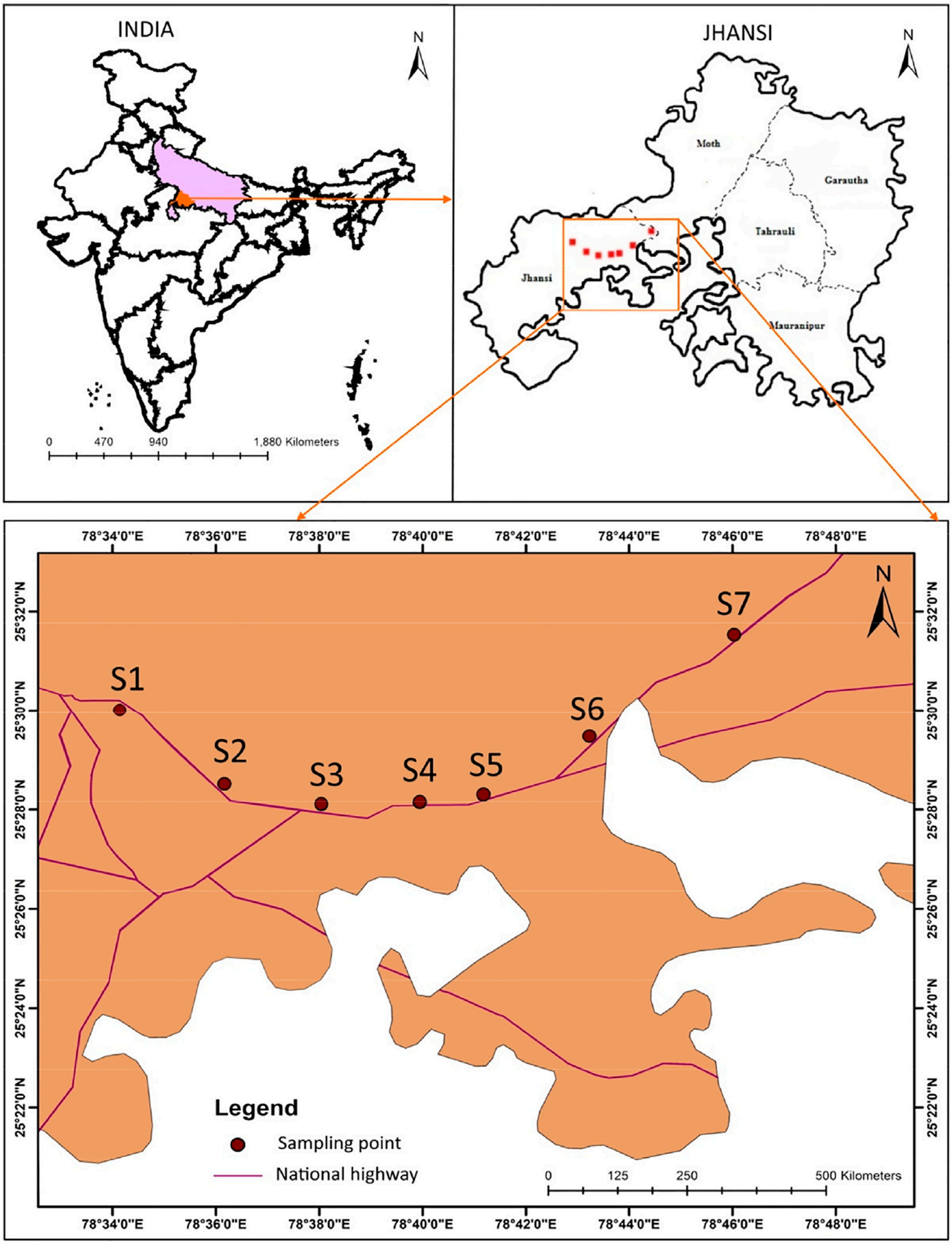

FIGURE 1 | A map of study area showing the locations of sampling points.

parameters analysis. The heavy metals contents were analyzed by atomic absorption spectrometry method using Perkin-Elmer AAnalyst 400, USA model after digestion of samples. The digestion (wet oxidation) process for soil and vegetables samples was done with the help of solution which was prepared by mixing one part of perchloric acid ($HClO_4$) and three part of conc. Nitric acid (HNO_3) (Guo et al., 2006; Singh and Praharaj, 2017).

TABLE 1 | Details of vegetable samples.

S. No	Common name	Botanical name	Edible part	Family
1	Coriander	*Coriandrum sativum*	Leaves	Apiaceae
2	Onion	*Allium cepa*	Bulb	Amaryllidaceae
3	Tomato	*Solanum lycopersicum*	Fruit	Solanaceae

Quality Check

The analysis of samples was done for quality control and assurance. The analytical-grade chemicals and reagents were used during entire analytical procedures. Double distilled water (DDW) was applied to prepare the required reagents, standards, and analytical samples processing and dilution. Calibration curves were produced for each investigated heavy metal. Blanks were also analyzed frequently to ensure analytical quality. Procedural washing at regular intervals was done using DDW during the entire analysis to avert any contamination in the equipment. The values of instrumental detection limit (IDL) were lower than the values of method detection limit (MDL) and method quantification limit (MQL) which signaled the good sensitivity of the instrument (atomic absorption spectrophotometer) for heavy metals estimation.

Bio-Concentration Factor of Heavy Metals

BCF of heavy metals from soils to vegetables was assessed by computing the ratio of the concentration of each heavy metal in vegetable's edible parts and the concentration of corresponding heavy metals in the respective soil. If BCF is less than 1, it suggests less movement of heavy metals from soil to vegetables. Conversely, BCF of more than one indicate the higher uptake of heavy metals by tested vegetable from soil (Sharma et al., 2018). It was assessed by following **Eq. 1**.

$$\text{Bio} - \text{concentration (BCF)} = C_V/C_S. \tag{1}$$

Where, C_v is the amount of heavy metals in vegetables on dry weight (DW) basis (mg/kg dw), while C_s is the amount of heavy metals (mg/kg dw) in soil samples.

Health Risk Assessment

The evaluation of possible level of any potentially harmful health effects occurring over a specified time period is known as "risk assessment" (Mohammadi et al., 2019). Based on the assessment of risk level, it can be categorized into carcinogenic and non-carcinogenic risks (Wongsasuluk et al., 2014). Carcinogenic risk assessment is a method of estimating the incremental probability of developing cancer over an individual's lifetime due to exposure to a potential carcinogenic metal (USEPA, 1991). According to IARC (2014), Cd, Ni, and Co were considered as carcinogenic metals in this study that have the potential to cause cancer when an individual is exposed to them for a lifetime (70 years). However, quantitative assessment of carcinogenic risk from oral exposure to these metals was not performed under the Integrated Risk Information System (IRIS) program (USEPA, 2021). Therefore, the carcinogenic risk assessment was not performed due to non-availability of oral slope factor (SF_O) for these metals.

Non-carcinogenic Health Risk Assessment

The heavy metals' non-carcinogenic risk to humans was determined by assessing the estimated daily intake (EDI) and target hazard quotient (THQ). However, the cumulative non-carcinogenic health hazard posed by exposure to a mixture of all investigated heavy metals was assessed by determining health risk index (HRI). EDI of heavy metals was evaluated using following **Eq. 2**.

$$\text{EDI} = \frac{C \times IR \times EF \times ED}{BW \times AT} \times 10^{-3} \tag{2}$$

Where EDI denotes estimated daily (everyday) intake of heavy metals (mg/person/day); BW stands for adult body weight considered as 70 Kg (USEPA, 1989); AT represents the average time of exposure for non-carcinogenic health risk, taken as ED × 365 = 25,550 days (USEPA, 1989); C signifies heavy metals content in vegetables estimated in the current study (mg/kg dw); IR is ingestion rate of vegetables regarded as 65 g/person/day for tomato, 60 g/person/day for onion, and 35 g/person/day for coriander (survey from local residents); EF and ED refers to the exposure frequency and exposure duration which were assumed as 365 days/year and 70 years, respectively (Sharma et al., 2018).

Target hazard quotient (THQ) measures aggregated non-cancerous risks because of heavy metals intake via regular ingestion of contaminated vegetables. THQ values <1 are supposed to have no non-carcinogenic risks. While, if the value of THQ >1, it is considered to have possibility of substantial health hazards. The health risk hazard is enhanced with the increased THQ (Antoine et al., 2017). THQ was determined by following **Eq. 3**.

$$\text{THQ} = \frac{\text{EDI}}{\text{RfD}} \tag{3}$$

Where RfD refers to oral reference dose which was taken as 1×10^{-3} for Cd, 3.5×10^{-3} for Pb, 2.0×10^{-2} for Ni, 2.0×10^{-2} for Co, 3×10^{-1} for Zn, 4.0×10^{-1} for Cu, and 4.6×10^{-2} for Mn (USEPA, 2021).

Health risk index (HRI) was estimated by following **Eq. 4**.

$$\text{HRI} = \sum \text{THQ} \tag{4}$$

Where THQ represents the target hazard quotient and can be computed by **Eq. 3**.

Statistical Analysis

The data obtained from the experimental analysis was simplified through principal component analysis (PCA) to speculate the sources of heavy metals in the vegetables of the study area. It was

TABLE 2 | Average concentration (mg/kg) of heavy metals in soil and vegetable samples of the study area (N = 28) on dry weight (dw) basis.

Samples	Index	Cd	Pb	Ni	Co	Zn	Cu	Mn
Soil	Mean ± SD	2.02 ± 2.00	19.09 ± 4.77	21.56 ± 9.38	9.31 ± 3.23	35.34 ± 5.83	14.96 ± 6.12	15.21 ± 6.05
	Range	0.77–5.06	9.09–22.59	12.21–34.09	6.42–15.02	29.10–41.33	5.57–24.34	9.21–22.20
Coriander	Mean ± SD	0.23 ± 0.07	2.12 ± 2.94	0.77 ± 0.46	0.47 ± 0.41	36.65 ± 6.66	5.92 ± 1.81	21.65 ± 7.32
	Range	0.14–0.44	0.71–12.52	0.31–2.39	0.03–1.33	26.45–49.70	3.30–10.60	9.33–33.84
Onion	Mean ± SD	0.13 ± 0.08	0.66 ± 0.60	0.54 ± 0.34	0.32 ± 0.30	23.94 ± 7.10	6.25 ± 3.16	20.15 ± 7.02
	Range	0.00–0.30	0.19–2.21	0.13–1.66	0.03–0.93	9.74–39.46	2.64–13.42	8.13–36.58
Tomato	Mean ± SD	0.14 ± 0.08	0.46 ± 0.50	0.89 ± 2.19	0.22 ± 0.25	16.77 ± 4.97	4.77 ± 1.82	14.46 ± 5.01
	Range	0.02–0.35	0.03–2.30	0.13–11.88	0.02–0.92	7.81–23.92	0.39–9.83	3.83–22.76
BGV[a]		0.90	13.10	27.70	15.20	22.10	56.50	209.00
USEPA (2002) [b]		0.48	200	72	—	1,100	270	—
Allowable limit[c]		0.05–0.2	0.1–0.3	10	50	50	10–40	500

[a]*BGV, is the background value for heavy metals in soils in India (Kumar V. et al., 2019); USEPA (2002).*
[b]*is the standards reference value for heavy metals in agricultural soils.*
[c]*Allowable heavy metals limit (mg/kg dw) in vegetables as described by Gebeyehu and Bayissa, 2020.*

TABLE 3 | Comparison of heavy metals concentration (mg/kg dw) in soil and vegetables with previous studies.

Sample type	Cd	Pb	Ni	Co	Zn	Cu	Mn	Point of sample collection	References
Soil	2.02	19.09	21.56	9.31	35.34	14.96	15.21	Vicinity of highway	Present study
	4.32	33.48	21.45	7.31	92.37	23.34	1,248.69	Industrial area	Ashraf et al. (2021)
	1.40	77.88	68.01	-	246.86	205.04	—	Industrial area	Moghtaderi et al. (2018)
	—	1.99	—	8.13	55.75	12.17	11.29	Bank of River	Muhammad et al. (2021)
Coriander	0.23	2.12	0.77	0.47	36.65	5.92	21.65	Vicinity of highway	Present study
	BDL	62.42	—	—	49.86	21.43	142.63	Waste-water irrigation	Ramesh and Murthy (2012)
	—	6.25	9.43	—	42.40	16.80	—	Waste-water irrigation	Khan et al. (2018)
Onion	0.13	0.66	0.54	0.32	23.94	6.25	20.15	Vicinity of highway	Present study
	—	—	4.74	—	33.46	70.71	—	Super-market	Cherfi et al. (2016)
	—	0.45	—	—	5.48	3.94	9.96	Reference/control site	Filimon et al. (2021)
	0.05	BDL	—	—	0.08	0.06	0.11	Local market	Ametepey et al. (2018)
Tomato	0.14	0.46	0.89	0.22	16.77	4.77	14.46	Vicinity of highway	Present study
	0.37[a]	2.19[a]	—	—	11.20[a]	1.56[a]	—	Industrial area	Haque et al. (2021)
	0.06	0.60	—	—	29.80	1.28	—	Local market	Zafarzadeh et al. (2018)

[a]*Heavy metals concentration in mg/kg fresh weight (fw).*

analyzed by the software, Statistical Package for Social Sciences (SPSS, Version 20.0). PCA involves extracting linear composites of observed variables. It allows the dataset for dimension reduction while keeping a maximum amount of information.

RESULTS AND DISCUSSION

Levels of Heavy Metals in Soil

The concentration levels of heavy metals in soil showed a higher inequality. The average amount of heavy metals in soil decreased in the sequence of Zn > Ni > Pb > Mn > Cu > Co > Cd (**Table 2**). The levels of Ni, Pb, Cu, and Zn were noted under the safe limit of India's standards as reported by Awasthi (2000) and USEPA (2002). However, Cd concentration was exceeding USEPA (2002) standards but under the India's standards as reported by Awasthi (2000) for agricultural soils. It is also worth noting that the average contents of Ni, Co, Cu, and Mn were less than the background values of soil of India while Cd, Pb, and Zn contents were higher than the background values of soil of India (**Table 2**). The Cd, Co, and Cu concentrations were highest at sampling site three whereas the accumulation of Zn and Pb was greatest by the soil of sampling site 5. Furthermore, the accumulated amount of Ni and Mn was richest in the samples picked up from sampling site 2 and 1, respectively. The maximum concentrations of Cd and Cu correspond with the results reported in a previous study (Ashraf et al., 2021). The concentration of Pb may be high due to the accumulation of pollutants from vehicles. The use of lead arsenate pesticides can also increase the concentration of Pb in the soil. The mean concentration of Pb, Co, Cu, and Ni attained in the present study was higher than those from the values reported by Muhammad et al. (2021) for agricultural soil samples. In contrast, it was very much lesser than the values reported by Moghtaderi et al. (2018) (**Table 3**).

Levels of Heavy Metals in Coriander, Onion, and Tomato

The sequence of average concentrations of heavy metals in coriander exhibited the following pattern: Zn > Mn > Cu > Pb > Ni > Co > Cd. The concentration of Cu was observed highest at sampling site S5 and lowest at sampling site S4. The results of this study were several folds lower than the results obtained by Sharma et al. (2016) and Tefera and Teklewold (2021) for coriander leaves and seeds, respectively. In the present study concentration of Mn was found lower (21.65 mg/kg dw) than the value reported by Ramesh and Murthy (2012). The Cd concentration obtained in the current study (0.23 mg/kg dw) exceeded the permissible limit at all sites. When compared with the previous research findings, the Cd values obtained in this study were less than the values reported by Sharma et al. (2016). However, it was higher than that of values reported by Kladsomboon et al. (2020). In our study, Pb concentration was found much higher at all sites than the permissible limit of 0.1–0.3 mg/kg dw compared to the value reported by Gebeyehu and Bayissa (2020). However, the present study results resembled the results obtained by Khan et al. (2018). The Ni content in coriander samples at all sites was found well within the allowable limit of 10 mg/kg dw reported by Gebeyehu and Bayissa (2020) for vegetables. Baig et al. (2018) reported that Ni concentration ranged from 6.14–9.43 mg/kg dw in the coriander leaves collected from Punjab, Pakistan (Khan et al., 2018). The mean value of Co was found to be 0.47 mg/kg dw. Sharma et al. (2016) reported the Co concentration up to 69 mg/kg dw in coriander from Punjab, India.

In onion, heavy metals concentration was exhibited in the order of Zn > Mn > Cu > Pb > Ni > Co > Cd. The concentration of Cu ranged between 2.64 and 13.42 mg/kg dw with a mean value of 6.25 mg/kg dw. Filimon et al. (2021) reported a Cu concentration of 3.94 mg/kg dw in onions collected from a copper mining area in Eastern Serbia. The concentration of Mn in onion in the present study (20.15 mg/kg dw) is very much higher than reported in Romania (0.33–4.07 mg/kg dw) (Manea et al., 2020), Ghana (0.07–0.015 mg/kg dw) (Ametepey et al., 2018); Eastern Serbia (9.96 mg/kg dw) (Filimon et al., 2021), and Nigeria (4.26 mg/kg dw) (Muhammad et al., 2021). The range of Zn concentration in the present study was close to the results (11.4–25.5 mg/kg dw) obtained by Amin et al. (2013). The greatest amount of Zn in the present study was noticed at S6. The average concentrations of Cd in both seasons were much higher than the permissible limit of 0.05 mg/kg dw set by FAO/WHO (2019) for bulb vegetables. In the present work, the range and mean values of Cd in onion were in line with the work done by Islam et al. (2016), where the range of Cd was 0.06–0.25 mg/kg dw with an average value of 0.14 mg/kg dw. The concentrations of Pb in onion at all sites exceeded the allowable limit of 0.1 mg/kg dw prescribed by FAO/WHO (2019) for bulb vegetables. The mean values of Pb obtained in the present study resemble the results obtained by Islam et al. (2016). Contrary to this, the concentration of Ni was several folds lower than reported in France (4.74 mg/kg dw) (Cherfi et al., 2016). The mean concentration of Co obtained in the present study (0.32 mg/kg dw) was much lesser than the results reported by Muhammad et al. (2021).

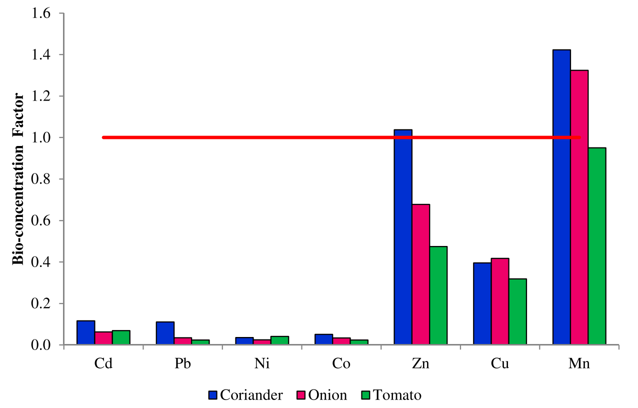

FIGURE 2 | Bio-concentration factor (BCF) of different heavy metals in different vegetables.

In tomato, heavy metals accumulation was found in order of Zn > Mn > Cu > Ni > Pb > Co > Cd as shown in **Table 2**. However, Cd concentrations exceeded the allowable limit of 0.05 mg/kg dw as notified by FAO/WHO (2019) for fruit vegetables. The amount of Pb and Ni was found to exceed the allowable limit, as described by Gebeyehu and Bayissa (2020). Co and Mn concentrations were observed many folds less than the permissible limit of FAO/WHO (2019). The level of Zn in tomatoes varied from 7.81 to 23.92 mg/kg dw. In this investigation, Zn in tomatoes was found higher than the value (3.57–9.25 mg/kg dw) reported in Algeria by Bounar et al., 2020. The value for Zn was slightly lower than that reported in Iran (29.80 mg/kg dw) by Zafarzadeh et al., 2018. The Cu concentration in all samples was well within the prescribed limit of 0.5 mg/kg dw.

Overall, the ranking of heavy metal concentrations investigated vegetables was as follows: coriander > onion > tomato. It is worth noting that the leafy vegetable coriander has accumulated more amounts of heavy metals followed by onion bulbs and tomato fruits. Similar trends were also reported by Letshwenyo and Mokokwe (2020), Gan et al. (2017), Sharma et al. (2016), and Zhou et al. (2016).

A comparison of the concentrations of Cd, Pb, Ni, Co, Zn, Cu, and Zn in soil and vegetables grown in the present study area with those reported in the literature shows that the heavy metals contents in the study area were lower than those collected from industrial areas or irrigated with wastewater. In contrast, the levels of heavy metals in the study area were higher than those collected from non-industrial areas and local market (**Table 3**). The heavy metals concentrations in vegetable samples collected from local market might be less due to the fact that local markets have the vegetables from different areas.

The Heavy Metal Bio-Concentration Factors

The heavy metal BCF is directly proportional to heavy metals in vegetables and their accumulation efficiency. However, it is

TABLE 4 | Principal component analysis (PCA) of heavy metals for various vegetables.

Metals	Principal components matrix			Metals	Rotated components matrix		
	PC1	PC2	PC3		PC1	PC2	PC3
Mn	0.99	0.06	−0.01	Zn	0.95	0.08	−0.19
Cu	0.61	0.30	0.35	Ni	0.88	−0.15	0.14
Zn	0.61	−0.69	0.30	Mn	0.64	0.57	0.50
Co	0.46	0.68	−0.17	Pb	−0.23	0.83	−0.11
Ni	0.59	−0.67	−0.11	Cu	0.25	0.72	0.10
Pb	0.24	0.64	0.54	Cd	0.06	−0.07	0.96
Cd	0.46	0.24	−0.82	Co	−0.19	0.57	0.59

Extraction sum of square loadings			Rotation sum of square loadings		
Total	% variability	% cumulative	Total	% variability	% cumulative
2.56	36.61	36.61	2.23	31.90	31.90
1.94	27.73	64.34	1.89	27.04	58.94
1.22	17.48	81.83	1.60	22.89	81.83

Component	Initial eigenvalues		
	Total	Variability (%)	Cumulative (%)
1	2.56	36.61	36.61
2	1.94	27.73	64.34
3	1.22	17.48	81.83
4	0.90	12.83	94.65
5	0.32	4.61	99.26
6	0.05	0.74	100.00

vice versa (inversely proportional) in the case of soil. Therefore, a BCF less than 0.1 suggest that a vegetable eliminates the respective heavy metal from its tissues (leaf, stem, root, fruit, and seed) (Bounar et al., 2020). However, the BCF ≥0.5 indicates that the soil and vegetables have been started to get contaminated by anthropogenic activities.

BCF of heavy metals were observed in decreasing order of Mn > Zn > Cu > Cd > Pb > Ni > Co with the highest and lowest values of 1.42 and 0.05 in coriander (**Figure 2**). The BCF of Cd, Pb, Ni, and Co was ≤0.2 in coriander at all sampling sites. In contrast, BCF of Cu at sampling site 2 (0.52) indicates that the site has been started to get contaminated by anthropogenic activities. Hence, it needs an attention to lower the heavy metals concentration in the area. However, the BCF of Mn and Zn has surpassed the value of one at almost all selected locations, revealing that the accumulation of heavy metals in coriander was greater than the accumulation in soil.

BCF of heavy metals in the onion bulbs were found in reducing order of Mn > Zn > Cu > Cd > Pb > Co > Ni. It is worth noting that for the onion samples at all sampling sites, BCF values for Cd, Pb, Ni, and Co were <0.1 (**Figure 2**). However, the accumulation of Mn in onion was higher than the accumulation in the soil at all sampling sites except S3 and S4. The bio-concentration factor for Zn was higher than 0.50 at all sites except S3 which reveals that accumulation of Zn has been initiated in onion. Whereas BCF of Cu was less than 0.50 at all sites except S5 and S6. The BCF of heavy metals in tomato were ranked as Mn > Zn > Cu > Cd > Ni > Pb > Co (**Figure 2**). However, BCF of all heavy metals were below the value of one which signifies less accumulation of these heavy metals in tomato. The research findings revealed that heavy metals accumulation varies in these vegetables. However, it was found that leafy vegetable coriander accumulates greater amounts of heavy metals than the onion bulb and tomato fruits.

Principal Component Analysis of Heavy Metals in Vegetables

Principal component analysis by varimax rotation method was applied on the data set of seven heavy metals to assume the sources of these metals in vegetables. The data extracted from PCA is given in **Table 4**, including component matrix, rotated component matrix, extraction sum of squared loadings, rotation sums of squared loadings, and initial eigenvalues. The first three principal components (PCs) accounted for 81.83% of the total variability. The first PC (PC-1) explained 36.61% with significant + ve loadings of Mn (0.99), Cu (0.61), Zn (0.61), and Ni (0.59). The contamination of Cu can occur due to the friction material used in the brake system of vehicles (Adamiec et al., 2016). However, tire wearing and corrosion of galvanized parts might contribute to the raised concentration of Zn (Taylor and Kruger, 2020). Currently, Zn is preferred for making wheel balancing weights to avoid leaded-wheel balancing weights. Besides the vehicular emission, a manufacturing unit of Portland cement (Mycem) is also situated in the study area which might be responsible for an elevated content of Cu, Ni, Co, and Pb. The cement plants use these metals as catalysts, modifiers, and dryers in the manufacturing process (Jan et al., 2010). In addition to this, a single super phosphate fertilizer industry is also located in the study area which might be responsible for the increased concentration of Zn and Pb in the study area. These facts signify that these heavy metals exist in the vegetables due to human-induced activities. It may include frequent chemical fertilizers and pesticides, vehicular emission, industrial discharge, etc. The

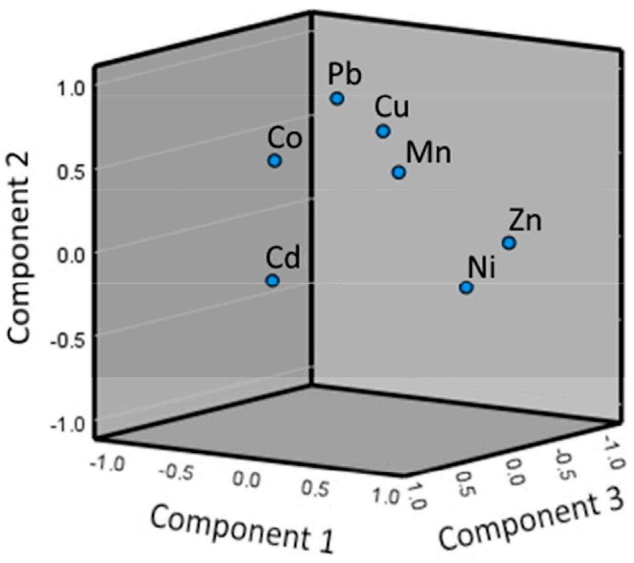

FIGURE 3 | The component plot in rotated space for heavy metals in the study area.

contribution of PC-2 was 27.73% to the total variance with high + ve loadings of Co (0.68) and Pb (0.64). Contrary to this, PC-2 was negatively loaded with Zn and Ni. However, the data showed that Cd and Co had a mixed source of origin in the study area (**Figure 3**).

Non-Carcinogenic Health Risks

The order of heavy metals with respect to EDI in coriander and onion is Zn > Mn > Cu > Pb > Ni > Co > Cd. However, for tomato, EDI of heavy metals was found in order of Zn > Mn > Cu > Ni > Pb > Co > Cd (**Table 5**). The results revealed that EDI of Cd, Pb, Zn, and Cu for coriander, onion, and tomato were within the provisional maximum tolerable daily intake (PMTDI) values as notified by FAO/WHO (2019). The highest and lowest EDI of Cu, Mn, Zn, Cd, Pb, Ni, and Co in coriander were 3.86E-03 at S2 and 2.11E-03 at S6, 1.41E-02 at S2 and 6.77E-03 at S6, 2.42E-02 at S7, and 1.49E-02 at S1, 1.63E-04 at S2 and 7.95–05 at S6, 2.07E-03 at S4 and 4.31E-04 at S5, 7.70E-04 at S2 and 2.56E-04 at S3, and 5.65E-04 at S2 and 3.54E-05 at S5, respectively (**Figures 4A,B**). It is worth noting that the EDI of all metals was highest at S2 except Zn and Pb in coriander which indicated the maximum involvement of human activities in the area. However, the EDI of Cu, Mn, Zn, Cd, Pb, Ni, and Co in onion were varied from 3.23E-03–8.68E-03, 9.11E-03–2.47E-02, 1.1. E-02–2.75E-02, 4.18E-06–1.73E-04, 2.00E-04–1.32E-03, 1.58E-04–8.93E-04, and 4.14E-05–6.13E-04, respectively (**Figures 5A,B**) It is worthy to note that the sequence of EDI of heavy metals in coriander and onion was similar, but the contribution was different. The maximum and minimum EDI values for Cu, Mn, Zn, Cd, Pb, Ni, and Co, of tomato, was 7.10E-03 at S2 and 2.75E-03 at S7, 1.80E-02 at S2 and 1.05E-03 at S1, 1.93E-02 at S3, and 8.52E-03 at S4, 2.43E-04 at S1 and 2.36E-05 at S5, 1.34E-03 at S2 and 3.81E-05 at S7, 3.38E-03 at S7 and 1.64E-04 at S5, and 5.45E-04 at S2 and 1.85E-05 at S6, respectively (**Figures 6A,B**).

The THQ of heavy metals resulting from coriander leaves intake was found to follow decreasing order of Pb > Mn > Cd >

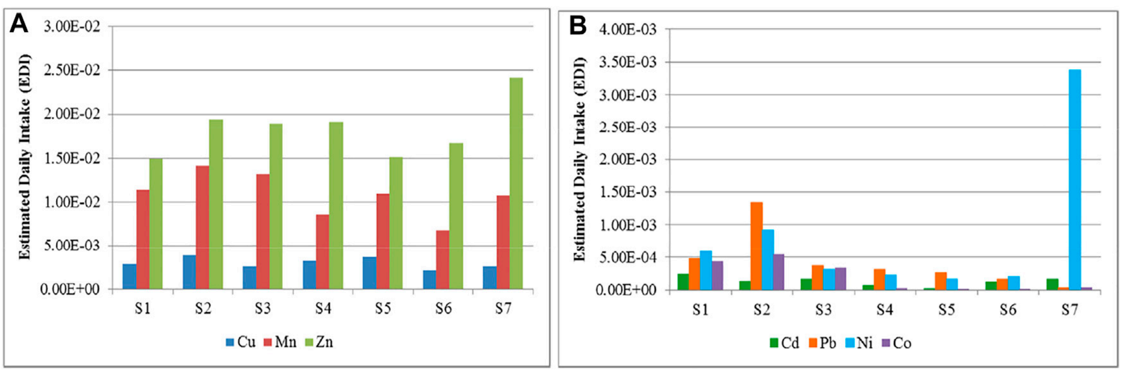

FIGURE 4 | (A,B) EDI of heavy metals in coriander at different sampling sites.

TABLE 5 | EDI due to consumption of different vegetables by adults.

Vegetables	EDI (mg/person/day)						
	Cu	Mn	Zn	Cd	Pb	Ni	Co
Coriander	2.96E-03	1.08E-02	1.83E-02	1.17E-04	1.06E-03	3.83E-04	2.36E-04
Onion	5.35E-03	1.73E-02	2.05E-02	1.09E-04	5.65E-04	4.63E-04	2.71E-04
Tomato	4.43E-03	1.34E-02	1.56E-02	1.29E-04	4.24E-04	8.25E-04	2.03E-04
FAO/WHO (2019)	5.00E-02 – 5.00E-01	—	3.00E-01–1.00E+00	2.00E-01	3.00E-01	—	—

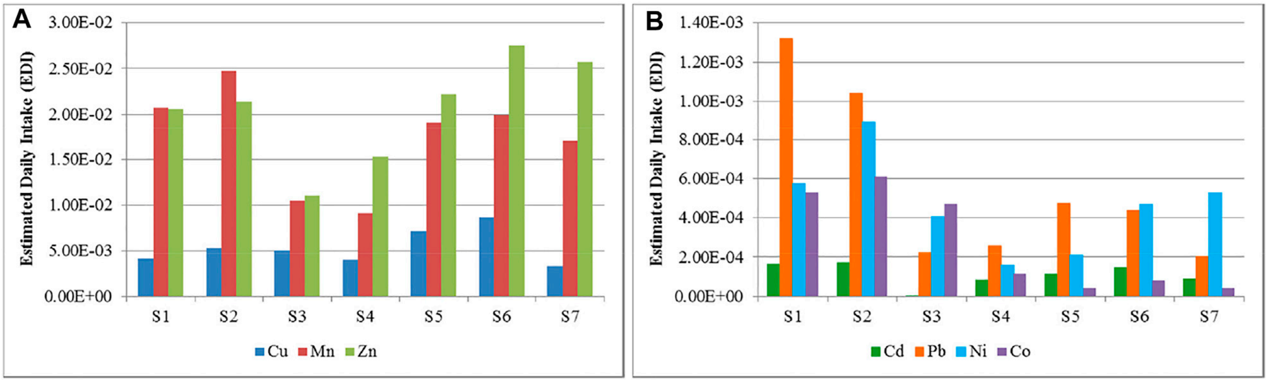

FIGURE 5 | (A,B) EDI of heavy metals in onion at different sampling sites.

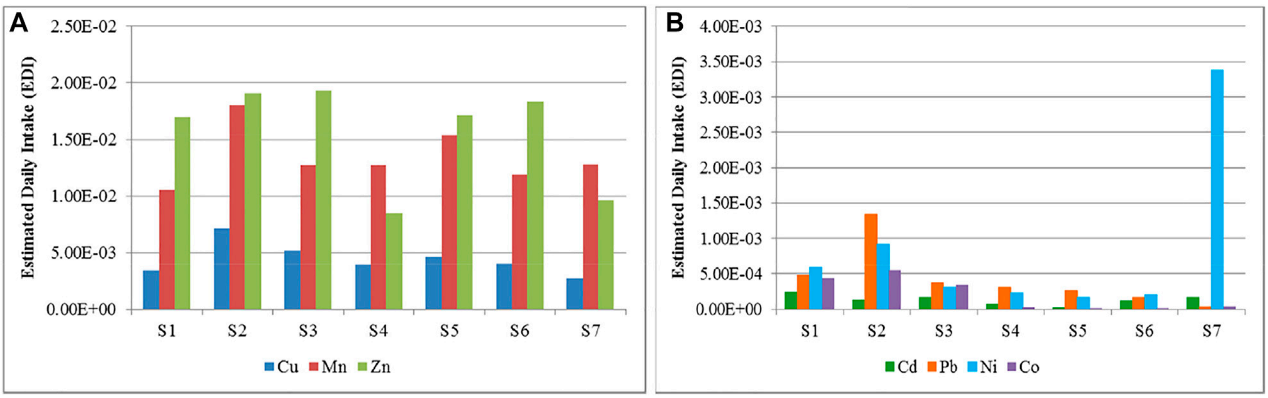

FIGURE 6 | (A,B) EDI of heavy metals in tomato at different sampling sites.

TABLE 6 | Target Hazard Quotient (THQ) of heavy metals for various vegetable crops.

Vegetables	THQ							HRI
	Cd	Pb	Cu	Mn	Zn	Ni	Co	
Coriander	1.17E-01	3.02E-01	7.40E-03	2.35E-01	6.11E-02	1.91E-02	1.18E-02	7.54E-01
Onion	1.09E-01	1.63E-01	1.34E-02	3.75E-01	6.84E-02	2.32E-02	1.37E-02	7.65E-01
Tomato	1.29E-01	1.21E-01	1.13E-02	2.92E-01	5.19E-02	4.13E-02	1.02E-02	6.57E-01

Zn > Ni > Co > Cu. In onion intake THQ of heavy metals was followed similar trends as Mn > Pb > Cd > Zn > Ni > Co > Cu. However, the sequence of THQ of heavy metals in tomatoes followed a pattern in the order of Mn > Cd > Pb > Zn > Ni > Cu > Co (**Table 6**). The THQ of Mn was highest in onion samples. It is noticeable that the highest THQ value was noted for Mn in onion. Despite the highest THQ of Mn in onion, it was not exceeding the safe value of 1. THQ of all analyzed heavy metals in coriander, onion, and tomato was under the safe value of 1, indicating that the vegetable consumption in these areas will not have any significant non-carcinogenic effects on humans.

The HRI value reflects the cumulative effects of various heavy metals in coriander, onion, and tomato consumption. Thus, it is evident from HRI that coriander, onion, and tomato consumptions are risk-free in the study area (**Table 6**). However, HRI value in coriander was slightly higher than the safe limit of one at S3 and S4 with their respective values of 1.03 and 1.01. Hence, it needs urgent attention to lower the heavy metals concentration in these sampling sites; otherwise, it may pose serious health hazards to humans in the near future.

CONCLUSION

The study results revealed that Cd, Pb, and Zn concentrations were higher than the Indian soil background values. In soil and coriander samples, Cd concentration exceeded the permissible limit. Likewise, the concentration of Pb exceeded the allowable concentration in coriander and onion. However, the average EDI and THQ of the study area for all investigated heavy metals were well within the permissible limit as notified by FAO/WHO (2019) for human consumption. But EDI and THQ values exceeded the safe limits at sampling sites two and 3. PCA analysis suggested that human activities plays vital role to the existing heavy metals concentration in the study area. Hence, it is strongly recommended to regularly monitor the soil and vegetable crops of the study area to avoid more accumulation, which may cause substantial non-carcinogenic health risks to the consumer of these vegetables in the near future.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

NG: Conceptualization, Methodology, Writing—Original Draft, Writing- Review and Editing. VK: Supervision. KY: Writing—Original Draft, Formal analysis. MC-P: Writing—Original Draft, Formal analysis. SP: Writing—Original Draft, Writing—Review and Editing. B-HJ and SK: Data curation, Formal analysis. MA: Formal analysis, Resources, Writing—Review and Editing. AA: Writing-Review and Editing.

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