Published in final edited form as:
. 2018 August ; 28(4): 666–679. doi:10.1016/S1002-0160(17)60440-5.

Transfer of Heavy Metals from Soils to Vegetables and Associated Human Health Risks at Selected Sites in Pakistan

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Abstract

Contamination of the food chain with heavy metals is considered as one of the major environmental pathways of human exposure to metals leading to potential health risks. This study aimed to investigate the concentrations of heavy metals such as copper (Cu), zinc (Zn), chromium (Cr), nickel (Ni), and manganese (Mn) in agricultural soils and food crops (fruit, leaf, and root vegetables), and their associated health risks to the local population in selected southern districts of Khyber Pakhtunkhwa Province, Pakistan. The concentrations of the selected metals in soil varied over a wide range, in the following decreasing order: Mn > Zn > Cr > Ni > Cu. The bioaccumulation of metals in vegetables was within the permissible risk limits, except for Cr which showed higher contamination in all the tested food crops. The trend of metal transfer factors for different vegetables was in the order of Cu > Ni > Cr > Mn > Zn, while the calculated daily intake of metals (DIM) in adults and children through consumption of food crops was in the decreasing order of Mn > Zn > Ni > Cr > Cu. The health risk index (HRI) values for the heavy metals for both adults and children were less than 1. Therefore, no significant health risk is anticipated for the local consumers through ingestion of these food crops.

Keywords

contamination; daily intake; food crops; metal accumulation; metal pollution; metal transfer factor; risk index

INTRODUCTION

Heavy metal contamination is considered as a dominant source of pollution and a potentially growing environmental and human health concern all over the world. These concerns have attracted tremendous attention, especially in developing countries (J¨arup, 2003; Atta *et al.*, 2009). Toxic metals enter the environment from both natural processes (volcanic eruptions, weathering, parent rock erosions, and atmospheric deposition, *etc.*) and anthropogenic activities (use of agro-chemicals, sewage disposal, mining, manufacturing, combustion of

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fossil fuels, compost application, and green manure) (Singh, 2001; Oti, 2015; Waqas *et al.*, 2015). These sources can cause contamination of both the soil and vegetables at high concentrations, leading to a number of potential impacts (Singh, 2001; Oti, 2015).

For example, heavy metals including both essential and non-essential elements have particular implications in eco-toxicology, since they all have the prospective to be lethal to living organisms (Storelli *et al.*, 2005). Some heavy metals like copper (Cu), zinc (Zn), and manganese (Mn) are essential for metabolic activities of animals and plants at some concentrations, but others such as chromium (Cr) and nickel (Ni) are toxic to plants, animals, and humans even at low concentrations. Thus, excessive accumulation of heavy metals in soils and plants poses risks to human health (Granero and Domingo, 2002; Yilmaz *et al.*, 2006; Khan *et al.*, 2008; Yasar *et al.*, 2010; Ramirez-Andreotta *et al.*, 2013a, b). Farmlands and vegetables contaminated with HMs such as Cu, Zn, Cr, Ni, and Mn have caused chronic effects on the regional eco-safety because of their persistence and long residence times in soils (Khan *et al.*, 2010; Muhammad *et al.*, 2011). In addition, the wide-spread existence of heavy metals not only alters the characteristics of agricultural soils, but also disturbs crop production and soil functions (An- gelovicova and Fazekasova, 2014).

Contamination of the food chain is one of the major environmental pathways of human exposure to heavy metals, leading to potential health risks. Heavy metal uptake by vegetables is mostly through the roots and leaves, with root uptake from the soil and soil solution the predominant process (Swartjes *et al.*, 2007; Chang *et al.*, 2014; Garg*et al.*, 2014). Heavy metal bioaccu- mulation in edible portions of food crops is an important source of contaminants into the human food chain, because vegetables absorb metals from the soil, air, and water (H´ector *et al.*, 2011; Chiroma *et al.*, 2014). Heavy metals enter the human body through various pathways including ingestion of edible crops or plant leaves splashed with polluted soils, accidental direct swallowing of heavy metals contaminated soil, and by inhalation of dust from contaminated soil (Essien and Hanson, 2014).

Therefore, proper agricultural practices and regular assessment of the accumulation of various heavy metals in agricultural soils and food crops are needed in order to minimize public health problems induced by ingestion of contaminated food crops. Crop production is a significant activity in the southern districts of Khyber Pakhtunkhwa (KP) Province, Pakistan, especially in Hangu, Kohat, Bannu, Lakki Marwat, and Dera Ismail (DI) Khan. However, until now, there has been no major systematic investigation of heavy metals in food crops and farmlands in this region of KP Province. It is therefore necessary to obtain a better understanding of metal accumulation in vegetables and agricultural soils as well as their possible health risks. Consequently, the aim of this study was to investigate the concentrations of metals in vegetables and agricultural soils that may have been impacted by multiple sources, including chemical fertilizers, pesticides, herbicides, sewage sludge, and wastewater irrigation. To our knowledge, this is the first study that has assessed the potential health risks of metal exposure in the vegetable growing areas in the study area. This study will provide reference data for policy decision-makers on the anticipation and treatment of metal pollution.

MATERIALS AND METHODS

Study area

The study area consists of selected southern districts of KP Province, Pakistan, such as Hangu, Ko-hat, Bannu, Lakki Marwat, and DI Khan, lying between 31.15° and 33.35° N and 70.11° and 72.01° E with total population of 1 343 020 (Fig. 1). The total cultivated land is 522 571 ha with very fertile farmland usually cultivated with a variety of crops and vegetables. Wheat, barley, maize, rice, sugarcane, cucumber, bitter melon, ridge gourd, onion, garlic, mint, lady finger, squash-melon, lettuce, spinach, pea, pumpkin, cabbage, cauliflower, potato, brinjal, turnips, pepper, carrot, radish, tomato, yam, purslane, Chinese onion, and coriander are the most important food crops grown in the study area (DCRs, 1998). The rivers Indus and Kurram and their tributaries as well as tube wells are the main sources of water for irrigation. The farmers sell their vegetables in the local market and also supply to other parts of the country.

Sampling and pre-treatment

Sampling sites were located in the selected districts of KP Province (Fig. 1). The coordinates of each site are provided in Table AI. Soil samples ($n = 175$) were collected from boreholes 20 cm deep and 10 cm in diameter, drilled with a stainless steel auger. Each soil sample comprised 5 sub-samples collected at distances of about 10 m from each other in different directions using the quartile method and mixed together to create a composite sample of 1 kg (Wu *et al*., 2010). The samples were put into sealed plastic bags and taken to the laboratory. After air drying, the soil samples were mechanically ground and passed through a sieve of 2-mm mesh, and preserved in clean zip sealed plastic bags for further chemical analyses.

Vegetables ($n = 175$) grown in the study area (Table I) were harvested from the same cultivated fields from where the soil samples were collected. The vegetable samples were packed into clean polyethylene bags and transported to the laboratory of the Department of Environmental Sciences, University of Peshawar, Pakistan. The collected samples were washed with double deionized water to eliminate air borne pollutants, dirt, and dust particles, then the edible parts of the samples were dried in the oven at 65 °C for 72 h until constant weight. The dried vegetable samples were powdered using an electronic grinder and stored in labeled paper bags for acid extraction and heavy metal analyses.

Sample extraction

The ground soil samples (1 g) were extracted using a wet digestion method (Khan *et al*., 2010), followed by addition of 15 mL aqua-regia ($HClO_4$, H_2SO_4, and HNO_3) with a 1:1:5 ratio into a 100 mL Teflon beaker and kept overnight. The next morning, the samples were heated on a hot plate to near dryness. After adding HClO4 (5 mL), the samples were heated again gradually to near dryness. Diluted acid solution was added and filtered through Whatman filter paper No. 42 into cleaned volumetric flasks (50 mL). The filtrates were diluted to 50 mL with double deionized water and stored for analysis.

The dried and powdered vegetable samples (2 g) were weighed in Pyrex beakers, and 10 mL of high grade HNO_3 was added and placed overnight at room temperature (Khan *et al.*, 2010), and dried till near dryness at 190 °C for 1.5 h on a hot plate. After cooling, 5 mL $HClO_4$ was added and the samples were heated slowly until the completion of the digestion process. The samples were filtered and diluted with double deionized water to required volume (50 mL) in clean volumetric flasks rinsed with acidified water. There-after, the samples were sealed and stored at room temperature for further analyses.

Analytical procedures

The heavy metal (Cu, Zn, Cr, Ni, and Mn) concentrations in the extracts of soil and vegetable samples were analyzed using the atomic absorption spectrophotometry (Perkin Elmer AAS-700). The analytical conditions of instrument are given in Table II. The selected vegetables of the study area were divided into three groups, fruit, leaf, and root vegetables, based on their edible portions. Analytical grade chemicals with a high spectroscopic purity of 99.9% (Merck Darmstadt, Germany) were used for sample preparation and analyses. Standard solutions of all five elements were prepared by diluting their corresponding 1 000 mg L^{-1} certified standard solutions (FlukaKamica, Busch, Switzerland). The blank reagents and standard reference soil (GBW-07406 (GSS-6)) and plant (GBW-07602 (GSV-1)) materials, purchased from the National Research Centre for Certified Reference Materials, China, of the selected metals were used to verify the accuracy and precision of the digestion method. For data quality assurance, each sample batch was analyzed in triplicate under optimal standard conditions within the confidence limit of 95%. Samples were extracted at the National Center of Excellence in Geology (NCEG), University of Peshawar, and the selected metals were determined in the Centralized Resource Laboratory (CRL), University of Peshawar.

Soil-to-plant metal transfer factor

The metal transfer factor (MTF), also termed the bioconcentration factor (BF), from soil to plant was computed as the ratio of the metal concentration in edible parts of the vegetable to the metal concentration in the soil. The required MTF was determined by the following equation (Cui *et al.*, 2005; Garg *et al.*, 2014):

$$\mathrm{MTF}=\mathrm{Cvegetable}/\mathrm{Csoil} \quad (1)$$

where *C*vegetable and *C*soil represent the metal conce trations in the extracts of the vegetable and soil samples, respectively, on a dry weight (DW) basis.

Daily intake of metals

The average daily intake of metals (DIMs) was calculated according to the following equation as used by Khan *et al.* (2008, 2010) and Jan *et al.* (2010):

$$\mathrm{DIM}=\frac{C\mathrm{m}\times C\mathrm{f}\times \mathrm{IRveg}}{\mathrm{Bw}} \quad (2)$$

where *C*m, *C*f , IRveg, and Bw represent the metal concentrations in vegetables (mg kg^{-1}), the conversion factor (0.085) for conversion of fresh weight to dry weight of the vegetables (Jan *et al.*, 2010), the ingestion rate of vegetable, and the average body weight, respectively. The average daily ingestion rate of food crops for adults (both male and female) and children were considered to be 0.345 and 0.232 kg $person^{-1}$ d^{-1}, respectively (Khan *et al.*, 2008, 2010), while the average adult and child body weights were considered as 73 and 32.7 kg, respectively (Jan *et al.*, 2010).

Health risk index

To estimate the chronic health risk, the human health risk index (HRI) for each metal resulting from contaminated food crop consumption was determined as follows (Khan *et al.*, 2008; Jan *et al.*, 2010):

$$\text{HRI} = \text{DIM}/\text{RfD} \quad (3)$$

where DIM and Rf D represent daily intake of the metal and reference dose of the metal, respectively. According to the US EPA (2005) database, the oral toxicity values of Rf D are 3.0×10^{-1}, 1.5, 2.0×10^{-2}, 3.7×10^{-2}, and 1.4×10^{-1} mg kg^{-1} d^{-1} for Zn, Cr, Ni, Cu, and Mn, respectively (US EPA, 2005; Shah *et al.*, 2012). The exposed population is considered to experience no significant risk when HRI is < 1 (Khan *et al.*, 2008; Muhammad *et al.*, 2011).

Statistical analysis

The data were statistically analyzed using the Microsoft Excel (2010) computer package. The measurements were expressed in terms of mean and standard deviation. The location map of the study area was pre pared using Arc-geographic information system (Arc- GIS).

RESULTS AND DISCUSSION

Heavy metal concentrations in soils

Table III summarizes the concentrations of the selected heavy metals on DW basis in the cultivated soil samples collected from the five districts (Bannu, DI Khan, Kohat, Hangu, and Lakki Marwat) of the study area. The concentrations of the selected metals ranged from approximately 1 to 340 mg kg^{-1} across the study area, and showed a decreasing order of Mn $>$ Zn $>$ Cr $>$ Ni $>$ Cu. The mean concentrations in soil samples ranged from 11.1 to 16.8, 108 to 134, 18.1 to 42.8, 21.2 to 39.3, and 258 to 285 mg kg^{-1} for Cu, Zn, Cr, Ni, and Mn, respectively, exhibiting a relatively small variation among the five districts. These findings indicate that the soils across the study area are contaminated with various heavy metals, which may be attributed to applications of fertilizers, pesticides, herbicides, and other potential sources.

Copper is an essential element required for the growth of plants (in the range of 4–20 mg kg^{-1}). Conversely, concentrations greater than 100 mg kg^{-1} are considered toxic as determined by the maximum allowable limits (MAL) set by State Environmental Protection

Administration, China (SEPAC, 1995) and by European Union (EU, 2000). The highest value (37.2 mg kg^{-1}) of Cu was observed in the soil of DI Khan, while the lowest concentration (4.68 mg kg^{-1}) was observed in the soil of Kohat. Thus, the measured Cu concentrations were below the MAL (100 mg kg^{-1}). The measured Cu concentrations were also lower than those reported by Khan *et al.* (2010) in Gilgit, northern Pakistan, and higher than those reported by Khan *et al.* (2013) in Swat District, northern Pakistan. Similar results were observed for Zn, which is also an essential element for vegetable growth. The highest Zn concentration (217 mg kg^{-1}, observed in soil samples collected from DI Khan) was below the MAL (300 mg kg^{-1}) set by SEPAC (1995). The highest mean concentrations measured for Ni (39.3 mg kg^{-1}) and Cr (42.8 mg kg^{-1}) were also lower than the MALs (60 and 150 mg kg^{-1}, respectively) (Table III). The mean Mn concentrations ranged from 258 to 285 mg kg^{-1} (Table III), which may be attributed to the geology of the area and optimum application of Mn based fertilizers, pesticides, and other agro-chemicals by local farmers. However, no MAL of Mn is available for comparison.

Heavy metal concentrations in vegetable crops

Table IV summarizes the data of the selected heavy metals on DW basis in edible portions of different vegetable species collected from the agricultural farms of the same five districts from where the soil samples were collected. The results were compared with the MALs set for the vegetables and other food crops by SEPAC (2005). The MAL concentrations for Cu, Zn, Cr, Ni, and Mn in food crops are 20, 100, 0.5, 10, and 500 mg kg^{-1}, respectively, on DW basis (SEPAC, 2005).

The metal concentrations were observed to vary greatly among the different vegetables collected from the study area. The mean concentrations of Cu in the vegetables grown in the study area ranged from 2.94 to 19 mg kg^{-1} (Table IV). Concentrations of Cu for all the vegetables belonging to the three groups of fruit, leaf, and root vegetables were lower than the MAL (20 mg kg^{-1}) set by SEPAC (2005). A low concentration (5–20 mg kg^{-1}) of Cu is required for normal growth of plants (Shah *et al.*, 2010). A concentration of Cu less than 5 mg kg^{-1} is considered inadequate for the growth of many vegetables and could affect the nutritional value (Kabata-Pendias and Pendias, 2001; Shah *et al.*, 2010), while a concentration of Cu greater than 20 mg kg^{-1} is considered phytotoxic (SEPAC, 2005).

High variations were observed in the concentrations of Zn in different vegetables collected from the study area (Table IV). Moreover, the mean concentrations of Zn also varied greatly from site to site. The mean concentrations of Zn ranged from 9.07 to 44.6 mg kg^{-1}, with the highest value observed for *Allium chinense*. The Zn concentrations for all the collected vegetable samples were also below the MAL (100 mg kg^{-1}) set by SEPAC (2005). Although Zn is an essential element for many physiological processes and metabolic activities of plants, it is toxic when present at elevated concentrations, causing chlorosis in leaves (Shah *et al.*, 2012). According to Wang *et al.* (2009), Zn reduces chlorophyll content and is responsible for damaging roots and living cells in shoots of various plants.

The mean concentrations of Ni ranged from 1.01 to 28.6 mg kg^{-1} for the different vegetables grown in the study area (Table IV). The highest Ni concentration was detected in Cucumis sativus, whereas the lowest concentration was detected in Pisum sativum. The Ni concentrations were lower than the MAL (10 mg kg^{-1}) set by SEPAC (2005) in China for all samples except C. sativus (28.5 mg kg^{-1}).

The mean concentrations of Mn (Table IV) in all the collected vegetable samples were higher compared to those of Cu, Zn, Cr, and Ni, and ranged from 33.7 to 171 mg kg^{-1}. However, the Mn concentrations for all samples of the vegetables were below the MAL (500 mg kg^{-1}) recommended by FAO/WHO (Food and Agriculture organization of the United Nations/World Health Organization). Mn is an essential element for metabolic processes of plants and for normal growth, skeletal formation, and the normal reproductive function in humans and animals. Mn deficiency can cause diabetes, nervous instability, and disorder of bone, growth in infants and children, and rheumatic arthritis in adults.

The concentrations of Cr in edible parts of the vegetables collected from the five districts of study area also varied from species to species. The mean Cr concentrations varied from 0.65 to 26.6 mg kg^{-1} (Table IV). The highest Cr concentration was found in *C. sativus*, while the lowest concentration was observed in *P. sativum*. The measured Cr concentrations were greater than the MAL (0.5 mg kg^{-1}). Thus, HM contamination in the vegetables grown in the study area and in humans, through ingestion of these food crops, is possible. Cr is one of the contaminants of environmental concern that is listed as a priority pollutant and is considered as a top 20 contaminant by the US EPA (ATSDR, 2007; Oliveira *et al.*, 2014).

The concentrations of Cu in vegetables reported herein are lower than the values (27–65 mg kg^{-1}) reported by Del R´ıo-Celestino *et al.* (2006) for plants grown in soil contaminated with mine tailings. Like-wise, the Ni and Zn concentrations were also lower than the results reported by Khan *et al.* (2010) in the Gilgit area of Pakistan, but were higher than the values detected by Khan *et al.* (2013) in Swat District of northern Pakistan. The Cr concentrations observed in this study were higher than the Cr concentrations observed by Khan *et al.* (2013), and were less than the values reported by Shah *et al.* (2010). The Mn concentrations were also higher than those detected by Khan *et al.* (2013) in Swat District of northern Pakistan.

Metal transfer factor (MTF)

Metal transfer factor is considered one of the vital parameters for assessing human exposure to heavy metals *via* food ingestion and represents the bio-availability of metals in a particular soil-substrate to plant species (Garg *et al.*, 2014). Table V summarizes the values of MTF from soil to vegetables in the study area. The mean values of MTF for Cu, Zn, Cr, Ni, and Mn ranged from 0.21 to 1.48, 0.08 to 0.33, 0.02 to 0.82, 0.04 to 1.00, and 0.09 to 0.60, respectively. The MTF values for Cu were higher compared to those of the other selected metals, with wide variations among the vegetables and sampling locations (Table V). The sequence of MTF values of the selected metals in various vegetables was in the order of Cu $>$ Ni $>$ Cr $>$ Mn $>$ Zn.

The highest MTF values ($>$ 1) for Cu were observed for *Solanum lycopersicum*, *Solanum melongena*, *A chinense*, *Portulaca oleracea*, *and Solanum tuberosum*, while for Ni, the highest MTF value was observed in *C. sativus*. The MTF values lower than 1 were obtained for Cr, Zn, and Mn for all the vegetable species collected from the five districts of the study area. Plants with MTF values greater than 1 are often referred to as hyper accumulators. Differences in MTF values are thought to be due to the differences in soil properties, plant physiology, and environmental conditions of various sites in the study area. The MTF values varied highly for different heavy metals even in the same vegetable species (Table V), because the local climate and stage of plant maturity at the har- vesting time can also affect the transfer of heavy metals from agricultural soils to vegetables (Voutsa *et al.*, 1996; Garg *et al.*, 2014).

The MTF values observed in this study were higher for Cu and Zn and lower for Ni than those observed by Khan *et al.* (2010) in Gilgit, northern Pakistan. Similarly, MTF values of Cr and Zn were lower, while those of Cu, Mn, and Ni were higher than the results described by Khan *et al.* (2013) for Swat District, northern Pakistan. Previous studies have shown that higher concentrations of metals in agricultural soils increases the chances of contamination in food crops grown on such soils and vice versa (Mapanda *et al.*, 2007; Ramirez-Andreotta *et al.*, 2013a). Moreover, the present study also confirmed that the vegetables cultivated on highly contaminated soils contained higher concentrations of heavy metals compared to vegetables grown on less/non contaminated soils.

From the above data, it is clear that the food crops cultivated on the contaminated soils can take up appreciable levels of heavy metals in their edible portions than crops grown on less contaminated soils. The overall metal concentrations in individual vegetable species in the study area showed different values due to cultivation on different soils, which could be ascribed to the accumulation of the metals in soil and possible atmospheric deposition. The variation in heavy metal concentrations may be attributed to the metal levels in their associated soils. Moreover, it was detected that the higher contaminations of heavy metals in the green food crops used in this study were due to plant uptake of the metals from the soils on which they were grown.

Daily intake of metals through consumption of vegeta- bles and the associated health risks

It is important to estimate the level of human exposure to heavy metals by tracing the exposure routes of the contaminants. Several human exposure pathways including food chain, dermal contact, and inhalation are possible routes, but oral intake is considered to be the primary pathway for exposure *via* the food chain (Khan *et al.*, 2008; Garg *et al.*,2014). Table VI summarizes the calculated values of DIM for both adults and children on the basis of average daily ingestion of different food crops. The DIM values for all selected metals through ingestion of vegetables were below 1. The cal culated DIM values for children were larger compared to those of adults, which is consistent with the findings of Tewari and Pande (2013). The highest intakes of Mn, Zn, Ni, Cr, and Cu were calculated for *A. malvaceae*, *A. chinense*, *C. sativus*, *A. chinense, and C. sativus*, respectively, for both adults and children. The overall sequence of DIM for individual metals in adults and children through ingestion of cultivated vegetables was in the order of Mn > Zn > Ni > Cr > Cu for both adults and children.

Table VII shows the values of HRI calculated for the selected heavy metals through consumption of vegetables for both adults and children. The mean metal concentration for each food crop was used for calculating the HRI for adults and children for all vegetable species grown in the study area (Table VII). In all the five districts, the HRI trend through food crop ingestion was in the decreasing order of Ni > Mn > Cu > Zn > Cr. The maximum HRI (8.62×10^{-1}) was calculated for children through consumption of Ni present in *C. sativus*, while the minimum HRI (1.79×10^{-4}) was observed for Cr present in the same vegetable. All of the calculated HRI values were less than 1. This indicates that no significant health risk is anticipated through consumption of these tested vegetables (Muhammad *et al*., 2011).

Overall, the leaf vegetables had higher HRI values for Zn and Cu compared to fruit and root vegetables. The overall HRI of this study indicated that the values obtained were higher for children than for adults (Table VII) for most of the metals in various food crops. Therefore, it is suggested that the children may be more susceptible to metal exposure, compared to adults, through consumption of vegetables (Song *et al*., 2009). This conclusion is based on the assumption that, compared to adults, children had greater daily intake of vegetables relative to their body weight. These findings are in agreement with those reported by Song *et al*. (2009) in China. Ryan and Chaney (1995) reported that the assessment of potential health risks in children as a vulnerable group may be important in predicting risks for the highly exposed sub-population on the basis that if the worst case is acceptable, then the majority of the population may be protected.

CONCLUSIONS

In this study, highest heavy metal concentrations in the agricultural soils of the study area were observed for Mn followed by Zn, Cr, Ni, and Cu. All selected metals in various vegetables were lower than their respective MALs, with the exception of Cr. The trend of MTF for different vegetables was in the order of Cu > Ni > Cr > Mn > Zn. The DIM of the heavy metals in adults and children through consumption of the food crops was the lowest for Zn and the highest for Cu. The results of this study indicated that all the HRI values of the selected heavy metals were found within the safe limits (HRI < 1), with no significant health risk anticipated for the local consumers through ingestion of these vegetables grown in the study area. It is suggested that monitoring for heavy metals should be conducted regularly for all agricultural soils and food crops to determine the health risks caused by exposure to heavy metals. This will assure food safety and protect the public from consuming the contaminated food and health risks. Furthermore, the Government and other related institutions should implement preventive measures to control heavy metal contamination in cultivated soils and food crops to minimize human health risks.

ACKNOWLEDGEMENTS

This study was supported by the Directorate of Science and Technology, Khyber Pakhtunkhwa, Pakistan, and the Higher Education Commission, Islamabad, Pakistan. The contribution of Prof. Dr. Mark L. Brusseau was supported by the NIEHS Superfund Research Program (No. ES04940).

APPENDIX

TABLE AI Coordinates of sampling sites from where the soil and vegetable samples collected in selected districts of the study area

District	Site	Latitude	Longitude
Bannu	1: Marmraiz	32° 52′50.2′′ N	70° 41′45.3′′ E
	2: Mamraiz	32° 52′42.1′′ N	70° 41′45.8′′ E
	3: Khasanikala	33° 0′30′′ N	70° 38′3.7′′ E
	4: Khasanikala	33° 0′24.1′′ N	70° 38′9.4′′ E
	5: Lalozai	33° 1′11′′ N	70° 36′14.8′′ E
	6: Salehkhan Mandan	32° 57′34.4′′ N	70° 36′27.8′′ E
	7: Salehkhan Mandan	32° 57′34.1′′ N	70° 36′27.7′′ E
	8: Changa Mandan	32° 57′19.4′′ N	70° 36′11.5′′ E
	9: Changa Mandan	32° 57′18.6′′ N	70° 36′21.3′′ E
	10: Ghoraywala Zaman	32° 54′9.4′′ N	70° 43′0′′ E
	11: Sokarizota khan	32° 59′18.8′′ N	70° 35′14.9′′ E
	12: Shah Dev	32° 55′32.8′′ N	70° 36′26.9′′ E
	13: Gul Badankala	32° 55′42.9′′ N	70° 34′59.4′′ E
	14: Gul Badankala	32° 55′42.3′′ N	70° 35′0.5′′ E
	15: Hasankhail	32° 54′21.3′′ N	70° 46′28′′ E
	16: Hasankhail	32° 54′12.6′′ N	70° 49′47.9′′ E
	17: Merakhail	32° 56′8.4′′ N	70° 40′11.4′′ E
	18: Turki Baazar	33° 1′20.4′′ N	70° 36′37.3′′ E
	19: Soranikala	30° 1′5.1′′ N	70° 49′5.8′′ E
	20: Amandiumar	30° 1′01.3′′ N	70° 34′35.9′′ E
	21: Nusratkhail	33° 1′16.3′′ N	70° 33′21.1′′ E
	22: Sokari Zabta	32° 59′08.5′′ N	70° 35′14.9′′ E
	23: Sokari Zabta khan	32° 59′08.7′′ N	70° 35′11.6′′ E
	24: Sokari Zabta	32° 59′7.1′′ N	70° 35′17.1′′ E
DI	1: Jhoke Jhandeer	31° 37′54.8′′ N	70° 48′48.2′′ E
Khan	2: Himmat	31° 53′6′′ N	70° 53′10.9′′ E
	3: Himmat Singar	31° 53′40.7′′ N	70° 54′55.9′′ E
	4: Himmat Singar	31° 53′40.9′′ N	70° 54′55.5′′ E
	5: Toya Siyal	31° 50′13.7′′ N	70° 55′42.5′′ E
	6: Toya Siya	31° 50′13.2′′ N	70° 55′37.6′′ E
	7: Toya Siyal	31° 50′12′′ N	70° 55′38.1′′ E
	8: Haji Mora	31° 46′36.4′′ N	70° 50′38.0′′ E
	9: Haji Mora	31° 46′23.7′′ N	70° 50′33.4′′ E
	10: Mora Ali	31° 47′59.1′′ N	70° 53′57.9′′ E
	11: Daabwala	31° 48′23′′ N	70° 54′35′′ E
	12: Daabwala	31° 48′21.6′′ N	70° 54′32.6′′ E
	13: Daabwala	31° 48′22.3′′ N	70° 54′35.7′′ E

District	Site	Latitude	Longitude
	14: Mandi Chowk	31° 51′48′′ N	70° 53′35.4′′ E
	15: Choudwaan	31° 35′17.1′′ N	70° 21′50′′ E
	16: Choudwaan	31° 35′16.8′′ N	70° 21′48.2′′ E
	17: Musa Zai	31° 40′58′′ N	70° 21′9.6′′ E
	18: Gandi Ashik	31° 46′57.8′′ N	70° 29′53.3′′ E
	19: Himmat	31° 53′18.4′′ N	70° 55′16.5′′ E
	20: Himmat	31° 53′18.3′′ N	70° 55′15.4′′ E
	21: Himmat	31° 53′19′′ N	70° 55′13.6′′ E
	22: Himmat	31° 53′17.7′′ N	70° 55′14.4′′ E
	23: Mandra Saeedan	31° 56′6.8′′ N	70° 56′16.1′′ E
	24: Dhotra	31° 58′46.6′′	70° 58′8.8′′ E
	25: Sadeeq Akbar Town	32○ 6′8.8′′ N	70○ 58′32.8′′ E
	26: Sadeeq Akbar Town	32○ 6′8.6′′ N	70○ 58′33.5′′ E
	27: Sadeeq Akbar Town	32○ 6′10′′ N	70○ 58′30.7′′ E
	28: Wasti Balou-chnagar	31○ 48′13.7′′ N	70○ 54′19.2′′ E
	29: Mora Ali	31○ 47′59.3′′ N	70○ 53′58.9′′ E
	30: Mora Ali	31○ 47′55.9′′ N	70○ 53′59.5′′ E
	31: Sherpao	31○ 48′14.8′′ N	70○ 54′27.6′′ E
	32: Madina Colony	31○ 48′14.5′′ N	70○ 54′27.7′′ E
	33: Balouchnagar	31○ 48′16.3′′ N	70○ 54′25.8′′ E
	34: Panyala	32○ 14′39.9′′ N	70○ 52′26.9′′ E
	35: Panyala	32○ 14′41.2′′ N	70○ 52′25.2′′ E
	36: Panyala city	32○ 14′22.6′′ N	70○ 52′38.9′′ E
	37: Panyala	32○ 14′22.7′′ N	70○ 52′38.7′′ E
Kohat	1: Kharmatu	33○ 30′37.2′′ N	71○ 30′4.3′′ E
	2: Kharmatu	33○ 30′16.5′′ N	71○ 30′25.3′′ E
	3: Dodha	33○ 29′14.3′′ N	71○ 29′29.5′′ E
	4: Dodha	33○ 29′14.1′′ N	71○ 29′31.3′′ E
	5: Haji Abad	33○ 28′51.3′′ N	71○ 29′37.4′′ E
	6: Dodha	33○ 29′52.5′′ N	71○ 29′37.2′′ E
	7: Haji Abad	33○ 28′52.9′′ N	71○ 29′35′′ E
	8: Beli Tang	33○ 31′6.1′′ N	71○ 34′5.4′′ E
	9: Beli Tang	33○ 31′1.1′′ N	71○ 34′17.5′′ E
	10: Beli Tang	33○ 31′3.0′′ N	71○ 34′13.9′′ E
	11: By Pass Road	33○ 36′30.9′′ N	71○ 25′43.6′′ E
	12: Biyana	33○ 36′30.7′′ N	71○ 25′40.4′′ E
	13: Biyana	33○ 36′30.5′′ N	71○ 25′41′′ E
	14: By Pass Road	33○ 36′28.6′′ N	71○ 29′43.1′′ E
	15: By Pass Road	33○ 36′38.8′′ N	71○ 26′6.2′′ E
	16: Sheikhan	33○ 29′30.5′′ N	71○ 26′10.8′′ E

District	Site	Latitude	Longitude
	17: Sheikhan	33○ 29′29.2′′ N	71○ 26′8.1′′ E
	18: Jerma	33○ 29′28.1′′N	71○ 26′6.2′′ E
	19: Jerma	33○ 29′25.7′′ N	71○ 25′59′′ E
	20: Ustarzai	33○ 36′8.2′′ N	71○ 15′35.8′′ E
	21: Ustarzai	33○ 36′6.9′′ N	71○ 15′35.7′′ E
	22: Ustarzai	33○ 36′18.4′′ N	71○ 15′19.4′′ E
	23: Ustarzai	33○ 36′19.7′′ N	71○ 15′20.8′′ E
	24: Ustarzai Payan	33○ 36′18.7′′ N	71○ 15′20.7′′ E
	25: Sorgul	33○ 30′28.5′′ N	71○ 23′20.4′′ E
	26: Sorgul	33○ 30′26.8′′ N	71○ 23′27.5′′ E
	27: Manduri	33○ 25′37′′N	71○ 22′40.5′′ E
	28: Manduri	33○ 25′37.7′′ N	71○ 22′47.2′′ E
	29: Muslim Abad	33○ 28′55.2′′ N	71○ 24′50.7′′ E
	30: Muslim Abad	33○ 28′51.2′′ N	71○ 25′7.0′′E
	31: Cadet College Togh	33○ 32′13.3′′N	71○ 30′14.4′′ E
	32: Kaghazai	33○ 35′8.1′′N	71○ 22′13.4′′ E
	33: Anbar Banda	33○ 35′14.21′′ N	71○ 22′12.5′′ E
	34: Mian Gari	33○ 36′28.3′′ N	71○ 21′52.45′′ E
	35: Muhammad Zai	33○ 36′21.4′′ N	71○ 21′48.4′′ E
	36: Barachgan Banda	33○ 36′10′′N	71○ 21′48.9′′ E
	37: Mir Ahmad khail	33○ 34′59.7′′ N	71○ 27′36.7′′ E
	38: Mir Ahmad Khail	33○ 34′53.4′′ N	71○ 27′33.9′′ E
	39: Gumbat	33○ 29′53.2′′ N	71○ 40′59.6′′ E
	40: Gumbat	33○ 30′0.3′′ N	71○ 40′40.1′′ E
	41: Gumbat	33○ 29′58.6′′ N	71○ 40′47.0′′ E
	42: Gumbat	33° 30′12.1′′ N	71° 41′61′′ E
	43: Gumbat	33° 30′9.5′′ N	71° 41′5.1′′ E
	44: Siyab	33° 29′26.1′′ N	71° 37′41.2′′ E
	45: Siyab	33° 29′24.9′′ N	71° 37′42.6′′ E
	46: Siyab	33° 29′18.1′′ N	71° 37′30.8′′ E
	47: Khwasi Banda	33° 28′58.6′′ N	71° 28′43.1′′ E
Lakki Marwat	1: Mamikhail	32° 50′15.4′′ N	70° 46′54.3′′ E
	2: Mamikhail	32° 50′52.6′′ N	70° 46′4.3′′ E
	3: Khaisoorkala	32° 43′33.4′′ N	70° 47′44.5′′ E
	4: Khaisoorkala	32° 47′52.6′′ N	70° 47′41.0′′ E
	5: Gambela	32° 37′22.5′′ N	70° 54′28.3′′ E
	6: Ehsanpur	32° 37′16.5′′ N	70° 54′28.5′′ E
	7: Ehsanpur	32° 37′19.4′′ N	70° 54′25.5′′ E
	8: Ehsanpur	32° 37′21.1′′ N	70° 54′26.6′′ E
	9: Ehsanpur	32° 37′24.6′′ N	70° 54′26.2′′ E

District	Site	Latitude	Longitude
	10: Manjiwala	32° 44′45.9′′ N	70° 50′17.2′′ E
	11: Manjiwala	32° 43′5.8′′ N	70° 50′25.6′′ E
	12: Baazkala	32° 44′55.4′′ N	70° 47′32.1′′ E
	13: Baazkala	32° 44′52.7′′ N	70° 47′33.4′′ E
	14: Baazkala	32° 44′53.3′′ N	70° 48′10.5′′ E
	15: Tajori	32° 37′11.1′′ N	70° 34′2.9′′ E
	16: Adeenkhail	32° 37′15.5′′ N	70° 33′51.7′′ E
	17: Bachkan Ahmadzai	32° 40′14.7′′ N	70° 42′24.5′′ E
	18: Topikalakotka	32° 39′32.5′′ N	70° 45′23.3′′ E
	19: Rajukhailbe-gatajazai	32° 38′52.6′′ N	70° 45′6.8′′ E
	20: Malang Adda	32° 40′28.3′′ N	70° 46′22.3′′ E
	21: Lakki Marwat City	32° 36′47.9′′ N	70° 54′52.8′′ E
	22: Lakki Marwat City	32° 36′57′′ N	70° 54′57′′ E
	23: Kowaan	32° 36′58.6′′ N	70° 54′58′′ E
	24: Lakki Koyaan	32° 37′15.5′′ N	70° 55′13.8′′ E
	25: Kot Kashmir	32° 44′35.8′′ N	70° 42′40.4′′ E
	26: Jadeed Abad	32° 50′52′′ N	70° 46′9.2′′ E
	27: Khaisoorkala	32° 48′32.9′′ N	70° 47′29.7′′ E
	28: Khattakokala	32° 47′59.5′′ N	70° 4′26.4′′ E
Hangu	1: Dallan	33° 21′2.5′′ N	70° 40′0.7′′ E
	2: Thal	33° 21′30.3′′ N	70° 33′16.6′′ E
	3: Thal	33° 21′31.4′′ N	70° 33′16.1′′ E
	4: Thal	33° 21′30.1′′ N	70° 33′12′′ E
	5: Dallan	33° 21′53.8′′ N	70° 38′35.5′′ E
	6: Dallan	33° 21′53.8′′ N	70° 33′40.3′′ E
	7: Tughsarai	33° 27′21.3′′ N	70° 58′1.4′′ E
	8: Barabaskhail	30° 27′27.8′′ N	70° 58′50.2′′ E
	9: Tughsarai	33° 27′28.2′′ N	70° 58′50.7′′ E
	10: Tughsarai	30° 27′29.6′′ N	70° 58′4.1′′ E
	11: Tughsarai	33° 27′30.2′′ N	70° 58′52′′ E
	12: Tughsarai	33° 27′30′′ N	70° 58′52.2′′ E
	13: Hangu City	30° 32′4.6′′ N	71° 4′16.7′′ E
	14: Hangu City	33° 32′0.1′′ N	71° 4′24.4′′ E
	15: Babar Mela	33° 33′7.6′′ N	71° 7′36.4′′ E
	16: Babar Mela	33° 32′40.9′′ N	71° 5′9.5′′ E
	17: Mela Hangu	30° 32′21.4′′ N	71° 3′53.1 E
	18: Station	33° 32′21.3′′ N	71° 3′53.3′′ E
	19: Station	33° 32′20.7′′ N	71° 3′55′′ E
	20: Railway Road	33° 31′40.4′′ N	71° 3′43′′ E
	21: Railway Road	33° 31′49.3′′ N	71° 3′48.9′′ E

District	Site	Latitude	Longitude
	22: Malak Abad	33° 31′53.5′′ N	71° 3′45.9′′ E
	23: Doaba	33° 26′13.8′′ N	70° 43′41.8′′ E
	24: Darsamand	33° 25′53.8′′ N	70° 43′11.8′′ E
	25: Darsamand	33° 25′53.5′′ N	70° 43′3.5′′ E
	26: Karbogha	33° 21′22.8′′ N	70° 46′0.5′′ E
	27: Karbogha	33° 21′22.8′′ N	70° 46′0.5′′ E
	28: Doaba	33° 25′36.1′′ N	70° 44′53.2′′ E
	29: Tora Wari	33° 29′5.7′′ N	70° 42′19.4′′ E
	30: Tora Wari	33° 29′5.6′′ N	70° 42′18.9′′ E
	31: Tora Wari	33° 29′5.8′′ N	70° 42′19′′ E
	32: Tora Wari	33° 29′6.9′′ N	70° 42′19.6′′ E
	33: Tora Wari	33° 28′59.7′′ N	70° 42′2.2′′ E
	34: Naryab	33° 28′36.4′′ N	70° 47′10′′ E
	35: Naryab	33° 28′35.6′′ N	70° 47′9.3′′ E
	36: Shahukhail	33° 35′7.2′′ N	71° 9′17′′ E
	37: Shahokhail	33° 35′5.2′′ N	71° 9′16.2′′ E
	38: Lodhikhail	33° 35′15.5′′ N	71° 9′41.4′′ E
	39: Lodhikhail	33° 35′13.6′′ N	71° 9′55.8′′ E

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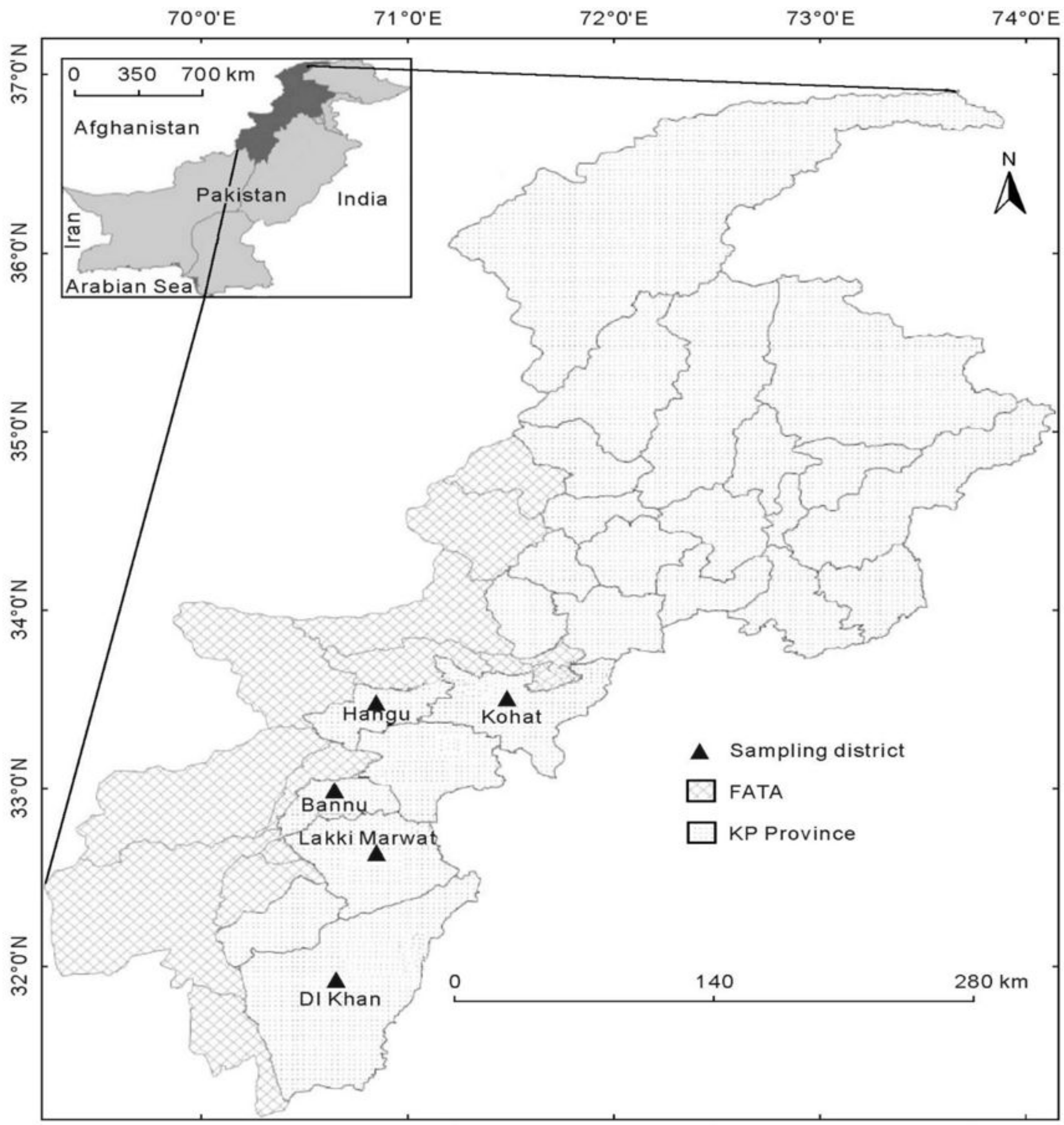

Figure 1.

Location map of the study area showing the sampling sites in the southern region of Khyber Pakhtunkhwa (KP) Province, Pakistan. FATA = Federally Administered Tribal Areas; DI = Dera Ismail.

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TABLE I

Description (botanical and vernacular names) of vegetables (n = 175) grown in the study area and their collecting seasons

Vegetable type	English name	Botanical name	Collecting season
Fruit vegetables	Bitter melon	*Momordica charantia*	Winter
(n = 79)	Ridge gourd	*Luffa acutangula*	Winter
	Tomato	*Solanum lycopersicum*	Summer
	Lady finger	*Aesculantus malvaceae*	Summer
	Cucumber	*Cucumis sativus*	Summer
	Brinjal	*Solanum melongena*	Winter
	Squash-melon	*Praecitrullus fistulosus*	Winter
	Cauliflower	*Brassica oleracea*	Winter
	Pumpkin	*Benincasa hispada*	Winter
	Pea	*Pisum sativum*	Winter
Leaf vegetables	Mint	*Mentha arvensis*	Summer
(n = 53)	Lettuce	*Lactuca sativa*	Summer
	Spinach	*Beta vulgaris*	Winter
	Cabbage	*Brassica oleracea*	Winter
	Coriander	*Coriandrum sativum*	Winter
	Chinese onion	*Allium chinense*	Winter
	Purslane	*Portulaca oleracea*	Winter
Root vegetables	Onion	*Allium cepa*	Winter
(n = 43)	Garlic	*Allium sativum*	Winter
	Radish	*Raphanus sativus*	Winter
	Turnip	*Brassica rapa*	Winter
	Carrot	*Daucus carota*	Winter
	Yam	*Colocasia esculanta*	Winter
	Potato	*Solanum tuberosum*	Winter

TABLE II

Analytical conditions of the atomic absorption spectrometry for analyses of selected heavy metals

Metal	Acetyene	Air	Wave-length	Slit width	Lamp current	Detection limit
	L min^{-1}		nm		mA	mg L^{-1}
Cu	2.0	17.0	324.8	0.7	15	1.5
Zn	2.0	17.0	213.9	0.7	15	1.5
Cr	2.5	17.0	357.9	0.7	25	3
Ni	2.0	17.0	232.0	0.2	25	6
Mn	2.0	17.0	279.5	0.2	20	1.5

TABLE III

Heavy metal concentrations in agricultural soil samples ($n = 175$) collected from the study area

Metal	District					MAL[b] (SEPAC, 1995)
	Bannu ($n = 24$)	DI Khan[a] ($n = 37$)	Kohat ($n = 47$)	Hangu ($n = 39$)	Lakki Marwat ($n = 28$)	
	mg kg^{-1}					
Cu	16.8 ± 3.47[c] (12.2–27.9)[d]	15.6 ± 7.12 (6.93–37.2)	11.1 ± 3.74 (4.68–27.8)	11.9 ± 2.75 (7.03–18.5)	13.4 ± 3.75 (8.20–22.3)	100
Zn	122 ± 20.6 (41.8–145)	134 ± 35.9 (91.7–217)	109 ± 19.8 (76.9–170)	119 ± 19.3 (82.1–175)	107 ± 24.1 (79.9–176)	300
Cr	42.8 ± 10.3 (0.93–55.1)	27.0 ± 12.8 (7.25–67.5)	18.1 ± 10.1 (3.00–40.4)	25.7 ± 9.17 (6.45–39.6)	32.4 ± 8.47 (10.7–47.2)	250
Ni	39.3 ± 9.15 (7.00–51.9)	26.7 ± 8.76 (12.5–46.3)	21.2 ± 6.16 (5.88–42.2)	22.8 ± 7.26 (11.6–36.6)	30.4 ± 7.50 (17.4–44.3)	60
Mn	285 ± 47.6 (65.7–317)	270 ± 34.4 (192–339)	258 ± 24.5 (158–294)	265 ± 28.7 (215–307)	266 ± 27.3 (214–318)	NA[e]

[a] Dera Ismail Khan.

[b] Maximum allowable limit.

[c] Means ± standard deviations.

[d] Values in the parentheses are the ranges.

[e] Not allotted.

TABLE IV

Heavy metal concentrations (on dry weight basis) in vegetable species (*n* = 175) collected from the study area

Vegetable species	Cu	Zn	Cr	Ni	Mn
	mg kg^{-1}				
Fruit vegetables (*n* = 79)					
M. charantia (*n* = 5)	10.4 ± 2.82[a)]	38.1 ± 20.0	3.36 ± 0.86	6.82 ± 1.98	102 ± 33.4
L. acutangula (*n* = 8)	12.2 ± 3.71	32.3 ± 17.9	2.04 ± 1.29	6.36 ± 2.50	87.2 ± 24.0
S. lycopersicum (*n* = 10)	19.0 ± 6.38	22.8 ± 6.64	2.72 ± 1.70	7.00 ± 2.54	144 ± 34.4
A. malvaceae (*n* = 13)	12.2 ± 2.42	34.7 ± 12.6	2.42 ± 0.96	5.25 ± 1.05	171 ± 62.8
C. sativus (*n* = 8)	11.9 ± 2.52	26.6 ± 7.44	26.6 ± 40.0	28.6 ± 37.4	110 ± 43.9
S. melongena (*n* = 7)	16.4 ± 4.55	21.6 ± 12.6	1.93 ± 0.93	5.27 ± 0.90	98.3 ± 21.8
P. fistulosus (*n* = 8)	10.1 ± 2.24	33.4 ± 15.3	3.82 ± 0.54	7.31 ± 1.28	89.1 ± 21.3
B. oleracea (*n* = 7)	2.94 ± 1.15	12.5 ± 8.91	1.72 ± 0.97	2.96 ± 1.65	80.9 ± 30.8
B. hispada (*n* = 7)	11.54 ± 1.81	26.6 ± 3.73	3.30 ± 1.23	7.69 ± 2.06	114 ± 49.8
P. sativum (*n* = 6)	5.42 ± 1.68	9.07 ± 3.56	0.65 ± 0.26	1.01 ± 0.59	33.7 ± 22.2
Leaf vegetables (*n* = 53)					
M. arvensis (*n* = 5)	12.5 ± 2.07	20.4 ± 4.58	1.74 ± 1.18	4.96 ± 2.74	125 ± 27.9
L. sativa (*n* = 4)	9.23 ± 2.68	15.8 ± 10.9	1.68 ± 1.06	3.99 ± 1.27	86.1 ± 34.4
B. vulgaris (*n* = 17)	9.15 ± 2.47	35.7 ± 27.1	1.74 ± 0.99	4.29 ± 2.56	141 ± 69.6
B. oleracea (*n* = 5)	3.50 ± 1.79	11.5 ± 7.3	1.55 ± 1.25	2.84 ± 1.35	75.1 ± 35.1
C. sativum (*n* = 10)	10.8 ± 5.02	24.9 ± 11.2	2.13 ± 1.43	3.94 ± 2.11	73.2 ± 33.0
A. chinense (*n* = 7)	18.2 ± 6.87	44.6 ± 4.98	3.52 ± 1.09	5.18 ± 2.21	107 ± 45.1
P. oleracea (*n* = 5)	18.7 ± 3.31	34.5 ± 26.1	2.81 ± 0.36	7.30 ± 2.10	74.4 ± 11.9
Root vegetables (*n* = 43)					
A. cepa (*n* = 5)	5.00 ± 0.95	14.2 ± 7.90	1.58 ± 1.07	4.43 ± 1.95	54.5 ± 33.7
A. sativum (*n* = 12)	5.48 ± 2.60	11.5 ± 5.91	1.05 ± 1.18	4.10 ± 7.78	35.8 ± 24.4
R. sativus (*n* = 8)	6.14 ± 5.74	20.9 ± 11.0	1.48 ± 0.70	3.00 ± 1.17	83.8 ± 49.9
B. rapa (*n* = 7)	4.19 ± 2.25	20.1 ± 23.1	2.23 ± 1.22	3.27 ± 1.62	81.3 ± 35.4
D. carota (*n* = 4)	4.63 ± 0.59	9.5 ± 3.27	1.23 ± 0.49	1.83 ± 1.08	34 ± 11.2
C. esculanta (*n* = 3)	8.86 ± 1.11	15.8 ± 0.51	2.20 ± 0.35	5.48 ± 1.38	168 ± 47.4
S. tuberosum (*n* = 4)	15.1 ± 4.54	23.7 ± 7.89	2.01 ± 1.01	4.15 ± 0.81	126 ± 23.9
MAL[b)] (SEPAC, 2005)	20	100	0.5	10	NA[c)]

[a)]Means ± standard

[b)]Maximum allowable limit.

[c)]Not allotted.

Table V

Metal transfer factors (MTFs) for vegetables grown in the study area

Vegetable species	Cu	Zn	Cr	Ni	Mn
Fruit vegetables (*n* = 79)					
M. charantia (*n* = 5)	0.70 ± 0.32[a)]	0.30 ± 0.51	0.09 ± 0.04	0.21 ± 0.18	0.36 ± 1.69
L. acutangula (*n* = 8)	0.73 ± 0.77	0.26 ± 0.40	0.07 ± 0.11	0.24 ± 0.28	0.34 ± 0.30
S. lycopersicum (*n* = 10)	1.58 ± 1.38	0.20 ± 0.31	0.10 ± 0.13	0.28 ± 0.25	0.53 ± 1.26
A. malvaceae (*n* = 13)	0.73 ± 0.34	0.26 ± 0.40	0.07 ± 0.08	0.17 ± 0.12	0.60 ± 2.45
C. sativus (*n* = 8)	0.82 ± 0.54	0.20 ± 0.24	0.82 ± 11.7	1.00 ± 19.81	0.38 ± 2.87
S. melongena (*n* = 7)	1.11 ± 0.62	0.19 ± 0.46	0.07 ± 0.06	0.18 ± 0.06	0.35 ± 1.06
P. fistulosus (*n* = 8)	0.82 ± 0.84	0.27 ± 0.63	0.13 ± 0.05	0.26 ± 0.25	0.32 ± 0.68
B. oleracea (*n* = 7)	0.24 ± 0.24	0.11 ± 0.26	0.06 ± 0.09	0.11 ± 0.23	0.31 ± 1.54
B. hispada (*n* = 7)	0.79 ± 0.55	0.22 ± 0.25	0.11 ± 0.11	0.29 ± 0.27	0.40 ± 3.59
P. sativum (*n* = 6)	0.40 ± 1.05	0.08 ± 0.40	0.02 ± 0.02	0.04 ± 0.04	0.12 ± 1.04
Leaf vegetables (*n* = 53)					
M. arvensis (*n* = 5)	0.96 ± 0.43	0.18 ± 0.17	0.06 ± 0.07	0.17 ± 0.19	0.47 ± 0.45
L. sativa (*n* = 4)	0.62 ± 1.01	0.14 ± 0.49	0.05 ± 0.07	0.13 ± 0.11	0.31 ± 1.20
B. vulgaris (*n* = 17)	0.84 ± 0.95	0.33 ± 1.91	0.08 ± 0.07	0.18 ± 0.25	0.57 ± 2.24
B. oleracea (*n* = 5)	0.21 ± 0.21	0.08 ± 0.15	0.05 ± 0.18	0.10 ± 0.18	0.30 ± 2.73
C. sativum (*n* = 10)	0.80 ± 1.16	0.21 ± 0.58	0.10 ± 0.10	0.17 ± 0.21	0.29 ± 1.11
A. chinense (*n* = 7)	1.38 ± 2.13	0.32 ± 0.17	0.13 ± 0.33	0.23 ± 1.92	0.39 ± 4.96
P. oleracea (*n* = 5)	1.27 ± 0.95	0.26 ± 0.90	0.10 ± 0.05	0.26 ± 0.67	0.26 ± 3.82
Root vegetables (*n* = 43)					
A. cepa (*n* = 5)	0.40 ± 0.17	0.12 ± 0.23	0.06 ± 0.07	0.18 ± 0.15	0.20 ± 0.81
A. sativum (*n* = 12)	0.49 ± 1.26	0.10 ± 0.40	0.04 ± 0.09	0.16 ± 0.73	0.16 ± 1.33
R. sativus (*n* = 8)	0.56 ± 2.38	0.20 ± 0.61	0.06 ± 0.08	0.12 ± 0.13	0.32 ± 1.64
B. rapa (*n* = 7)	0.31 ± 0.37	0.18 ± 1.36	0.12 ± 0.10	0.14 ± 0.18	0.31 ± 1.32
D. carota (*n* = 4)	0.39 ± 1.04	0.09 ± 1.85	0.03 ± 0.27	0.05 ± 0.20	0.15 ± 0.85
C. esculanta (*n* = 3)	0.51 ± 0.28	0.11 ± 0.02	0.05 ± 0.38	0.15 ± 0.29	0.56 ± 2.65
S. tuberosum (*n* = 4)	1.48 ± 9.15	0.22 ± 0.63	0.07 ± 0.13	0.17 ± 0.12	0.46 ± 1.51

[a)]Means ± standard deviations.

TABLE VI

Daily intake of metals (DIM) through consumption of different vegetables grown in the study area

Vegetable species	Individuals	Cu	Zn	Cr	Ni	Mn
Fruit vegetables				mg kg^{-1} d^{-1}		
M. charantia	Adults	4.29×10^{-3}	1.53×10^{-2}	1.35×10^{-3}	2.74×10^{-3}	4.13×10^{-2}
	Children	6.44×10^{-3}	2.29×10^{-2}	2.03×10^{-3}	4.11×10^{-3}	6.19×10^{-2}
L. acutangula	Adults	4.88×10^{-3}	1.30×10^{-2}	8.18×10^{-4}	2.55×10^{-3}	3.50×10^{-2}
	Children	7.32×10^{-3}	1.95×10^{-2}	1.23×10^{-3}	3.83×10^{-3}	5.26×10^{-2}
S. lycopersicum	Adults	7.61×10^{-3}	9.13×10^{-3}	1.09×10^{-3}	2.81×10^{-3}	5.81×10^{-2}
	Children	1.14×10^{-2}	1.37×10^{-2}	1.64×10^{-3}	4.22×10^{-3}	8.72×10^{-2}
A. malvaceae	Adults	4.88×10^{-3}	1.39×10^{-2}	9.71×10^{-4}	2.11×10^{-3}	6.87×10^{-2}
	Children	7.33×10^{-3}	2.09×10^{-2}	1.46×10^{-3}	3.17×10^{-3}	1.03×10^{-1}
C. sativus	Adults	4.76×10^{-3}	1.07×10^{-2}	1.07×10^{-2}	1.15×10^{-2}	4.42×10^{-2}
	Children	7.15×10^{-3}	1.60×10^{-2}	1.60×10^{-2}	1.72×10^{-2}	6.64×10^{-2}
S. melongena	Adults	6.58×10^{-3}	8.67×10^{-3}	7.76×10^{-4}	2.12×10^{-3}	3.95×10^{-2}
	Children	9.88×10^{-3}	1.30×10^{-2}	1.17×10^{-3}	3.18×10^{-3}	5.93×10^{-2}
P. fistulosus	Adults	4.03×10^{-3}	1.34×10^{-2}	1.53×10^{-3}	2.93×10^{-3}	3.58×10^{-2}
	Children	6.04×10^{-3}	2.01×10^{-2}	2.30×10^{-3}	4.41×10^{-3}	5.37×10^{-2}
B. oleracea	Adults	1.18×10^{-3}	5.02×10^{-3}	6.90×10^{-4}	1.19×10^{-3}	3.25×10^{-2}
	Children	1.77×10^{-3}	7.53×10^{-3}	1.04×10^{-3}	1.79×10^{-3}	4.88×10^{-2}
B. hispada	Adults	4.63×10^{-3}	1.07×10^{-2}	1.33×10^{-3}	3.09×10^{-3}	4.61×10^{-2}
	Children	6.96×10^{-3}	1.60×10^{-2}	1.99×10^{-3}	4.64×10^{-3}	6.92×10^{-2}
P. sativum	Adults	2.18×10^{-3}	3.64×10^{-3}	2.63×10^{-4}	4.05×10^{-4}	1.35×10^{-2}
	Children	3.27×10^{-3}	5.47×10^{-3}	3.95×10^{-4}	6.08×10^{-4}	2.03×10^{-2}
Leaf vegetables						
M. arvensis	Adults	5.02×10^{-3}	8.16×10^{-3}	6.97×10^{-4}	1.99×10^{-3}	5.01×10^{-2}
	Children	7.53×10^{-3}	1.23×10^{-2}	1.05×10^{-3}	2.99×10^{-3}	7.51×10^{-2}
L. sativa	Adults	3.71×10^{-3}	6.32×10^{-3}	6.73×10^{-4}	1.60×10^{-3}	3.46×10^{-2}
	Children	5.56×10^{-3}	9.49×10^{-3}	1.01×10^{-3}	2.40×10^{-3}	5.19×10^{-2}
B. vulgaris	Adults	3.67×10^{-3}	1.43×10^{-2}	6.99×10^{-4}	1.72×10^{-3}	5.67×10^{-2}
	Children	5.52×10^{-3}	2.15×10^{-2}	1.05×10^{-3}	2.59×10^{-3}	8.51×10^{-2}
B. oleracea	Adults	1.40×10^{-3}	4.60×10^{-3}	6.24×10^{-4}	1.14×10^{-3}	3.02×10^{-2}
	Children	2.11×10^{-3}	6.91×10^{-3}	9.37×10^{-4}	1.71×10^{-3}	4.53×10^{-2}
C. sativum	Adults	4.32×10^{-3}	1.00×10^{-2}	8.57×10^{-4}	1.58×10^{-3}	2.94×10^{-2}
	Children	6.48×10^{-3}	1.50×10^{-2}	1.29×10^{-3}	2.38×10^{-3}	4.41×10^{-2}
A. chinense	Adults	7.29×10^{-3}	1.79×10^{-2}	1.41×10^{-3}	2.08×10^{-3}	4.31×10^{-2}
	Children	1.09×10^{-2}	2.69×10^{-2}	2.12×10^{-3}	3.13×10^{-3}	6.46×10^{-2}
P. oleracea	Adults	7.50×10^{-3}	1.38×10^{-2}	1.13×10^{-3}	2.93×10^{-3}	2.99×10^{-2}
	Children	1.13×10^{-2}	2.07×10^{-2}	1.69×10^{-3}	4.40×10^{-3}	4.49×10^{-2}
Root vegetables						

Vegetable species	Individuals	Cu	Zn	Cr	Ni	Mn
A. cepa	Adults	2.01×10^{-3}	5.68×10^{-3}	6.36×10^{-4}	1.78×10^{-3}	2.19×10^{-2}
	Children	3.01×10^{-3}	8.53×10^{-3}	9.55×10^{-4}	2.67×10^{-3}	3.28×10^{-2}
A. sativum	Adults	2.18×10^{-3}	4.59×10^{-3}	4.25×10^{-4}	1.67×10^{-3}	1.65×10^{-2}
	Children	3.28×10^{-3}	6.90×10^{-3}	6.38×10^{-4}	2.51×10^{-3}	2.48×10^{-2}
R. sativus	Adults	2.47×10^{-3}	8.38×10^{-3}	5.93×10^{-4}	1.21×10^{-3}	3.36×10^{-2}
	Children	3.70×10^{-3}	1.26×10^{-2}	8.90×10^{-4}	1.81×10^{-3}	5.05×10^{-2}
B. rapa	Adults	1.68×10^{-3}	8.06×10^{-3}	8.95×10^{-4}	1.31×10^{-3}	3.26×10^{-2}
	Children	2.53×10^{-3}	1.21×10^{-2}	1.34×10^{-3}	1.97×10^{-3}	4.90×10^{-2}
D. carota	Adults	1.86×10^{-3}	3.83×10^{-3}	4.92×10^{-4}	7.33×10^{-4}	1.61×10^{-2}
	Children	2.79×10^{-3}	5.74×10^{-3}	7.39×10^{-4}	1.10×10^{-3}	2.41×10^{-2}
C. esculanta	Adults	3.56×10^{-3}	6.35×10^{-3}	8.84×10^{-4}	2.20×10^{-3}	6.78×10^{-2}
	Children	5.34×10^{-3}	9.54×10^{-3}	1.33×10^{-3}	3.30×10^{-3}	1.02×10^{-1}
S. tuberosum	Adults	6.04×10^{-3}	9.48×10^{-3}	8.07×10^{-4}	1.67×10^{-3}	5.06×10^{-2}
	Children	9.07×10^{-3}	1.42×10^{-2}	1.21×10^{-3}	2.50×10^{-3}	7.60×10^{-2}

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Table VII

Health risk index (HRI) for heavy metals caused by the consumption of different vegetables grown in the study area

Vegetable species	Individuals	Cu	Zn	Cr	Ni	Mn
Fruit vegetables						
M. charantia	Adults	1.16×10^{-1}	5.09×10^{-2}	9.00×10^{-4}	1.37×10^{-1}	2.95×10^{-1}
	Children	1.74×10^{-1}	7.65×10^{-2}	1.35×10^{-3}	2.06×10^{-1}	4.42×10^{-1}
L. acutangula	Adults	1.32×10^{-1}	4.33×10^{-2}	5.46×10^{-4}	1.28×10^{-1}	2.50×10^{-1}
	Children	1.98×10^{-1}	6.50×10^{-2}	8.19×10^{-4}	1.92×10^{-1}	3.75×10^{-1}
S. lycopersicum	Adults	2.06×10^{-1}	3.04×10^{-2}	7.29×10^{-4}	1.41×10^{-1}	4.15×10^{-1}
	Children	3.09×10^{-1}	4.57×10^{-2}	1.09×10^{-3}	2.11×10^{-1}	6.23×10^{-1}
A. malvaceae	Adults	1.32×10^{-1}	4.65×10^{-2}	6.47×10^{-4}	1.05×10^{-1}	4.90×10^{-1}
	Children	1.98×10^{-1}	6.97×10^{-2}	9.72×10^{-4}	1.58×10^{-1}	7.36×10^{-1}
C. sativus	Adults	1.29×10^{-1}	3.56×10^{-2}	7.11×10^{-3}	5.74×10^{-1}	3.16×10^{-1}
	Children	1.93×10^{-1}	5.34×10^{-2}	1.07×10^{-2}	8.62×10^{-1}	4.74×10^{-1}
S. melongena	Adults	1.78×10^{-1}	2.89×10^{-2}	5.17×10^{-4}	1.06×10^{-1}	2.82×10^{-1}
	Children	2.67×10^{-1}	4.34×10^{-2}	7.77×10^{-4}	1.59×10^{-1}	4.23×10^{-1}
P. fistulosus	Adults	1.09×10^{-1}	4.46×10^{-2}	1.02×10^{-3}	1.47×10^{-1}	2.55×10^{-1}
	Children	1.63×10^{-1}	6.70×10^{-2}	1.53×10^{-3}	2.20×10^{-1}	3.83×10^{-1}
B. oleracea	Adults	3.19×10^{-2}	1.67×10^{-2}	4.60×10^{-4}	5.95×10^{-2}	2.32×10^{-1}
	Children	4.79×10^{-2}	2.51×10^{-2}	6.91×10^{-4}	8.93×10^{-2}	3.48×10^{-1}
B. hispada	Adults	1.25×10^{-1}	3.56×10^{-2}	8.84×10^{-4}	1.54×10^{-1}	3.29×10^{-1}
	Children	1.88×10^{-1}	5.35×10^{-2}	1.33×10^{-3}	2.32×10^{-1}	4.94×10^{-1}
M. arvensis	Adults	5.88×10^{-2}	1.21×10^{-2}	1.75×10^{-4}	2.03×10^{-2}	9.65×10^{-2}
	Children	8.83×10^{-2}	1.82×10^{-2}	2.63×10^{-4}	3.04×10^{-2}	1.45×10^{-1}
Leaf vegetables						
M. arvensis	Adults	1.36×10^{-1}	2.72×10^{-2}	4.65×10^{-4}	9.96×10^{-2}	3.58×10^{-1}
	Children	2.03×10^{-1}	4.08×10^{-2}	6.98×10^{-4}	1.50×10^{-1}	5.37×10^{-1}
L. sativa	Adults	1.00×10^{-1}	2.11×10^{-2}	4.49×10^{-4}	8.00×10^{-2}	2.47×10^{-1}
	Children	1.50×10^{-1}	3.16×10^{-2}	6.73×10^{-4}	1.20×10^{-1}	3.71×10^{-1}
B. vulgaris	Adults	9.93×10^{-2}	4.78×10^{-2}	4.66×10^{-4}	8.62×10^{-2}	4.05×10^{-1}
	Children	1.49×10^{-1}	7.17×10^{-2}	7.00×10^{-4}	1.29×10^{-1}	6.08×10^{-1}
B. oleracea	Adults	3.80×10^{-2}	1.53×10^{-2}	4.16×10^{-4}	5.70×10^{-2}	2.15×10^{-1}
	Children	5.70×10^{-2}	2.30×10^{-2}	6.25×10^{-4}	8.56×10^{-2}	3.23×10^{-1}
C. sativum	Adults	1.17×10^{-1}	3.33×10^{-2}	5.71×10^{-4}	7.92×10^{-2}	2.10×10^{-1}
	Children	1.75×10^{-1}	5.00×10^{-2}	8.58×10^{-4}	1.19×10^{-1}	3.15×10^{-1}
A. chinense	Adults	1.97×10^{-1}	5.97×10^{-2}	9.42×10^{-4}	1.04×10^{-1}	3.08×10^{-1}
	Children	2.96×10^{-1}	8.96×10^{-2}	1.41×10^{-3}	1.56×10^{-1}	4.62×10^{-1}
P. oleracea	Adults	2.03×10^{-1}	4.61×10^{-2}	7.52×10^{-4}	1.47×10^{-1}	2.13×10^{-1}
	Children	3.04×10^{-1}	6.92×10^{-2}	1.13×10^{-3}	2.20×10^{-1}	3.20×10^{-1}

Vegetable species	Individuals	Cu	Zn	Cr	Ni	Mn
Root vegetables						
A. cepa	Adults	5.42×10^{-2}	1.89×10^{-2}	4.24×10^{-4}	8.90×10^{-2}	1.56×10^{-1}
	Children	8.14×10^{-2}	2.84×10^{-2}	6.37×10^{-4}	1.34×10^{-1}	2.34×10^{-1}
A. sativum	Adults	5.90×10^{-2}	1.53×10^{-2}	2.84×10^{-4}	8.36×10^{-2}	1.18×10^{-1}
	Children	8.86×10^{-2}	2.30×10^{-2}	4.26×10^{-4}	1.26×10^{-1}	1.77×10^{-1}
R. sativus	Adults	6.67×10^{-2}	2.79×10^{-2}	3.95×10^{-4}	6.03×10^{-2}	2.40×10^{-1}
	Children	1.00×10^{-1}	4.19×10^{-2}	5.93×10^{-4}	9.06×10^{-2}	3.61×10^{-1}
B. rapa	Adults	4.55×10^{-2}	2.69×10^{-2}	5.97×10^{-4}	6.57×10^{-2}	2.33×10^{-1}
	Children	6.83×10^{-2}	4.03×10^{-2}	8.96×10^{-4}	9.86×10^{-2}	3.50×10^{-1}
D. carota	Adults	5.02×10^{-2}	1.28×10^{-2}	3.28×10^{-4}	3.67×10^{-2}	1.15×10^{-1}
	Children	7.54×10^{-2}	1.91×10^{-2}	4.92×10^{-4}	5.50×10^{-2}	1.72×10^{-1}
C. esculanta	Adults	9.62×10^{-2}	2.12×10^{-2}	5.89×10^{-4}	1.10×10^{-1}	4.84×10^{-1}
	Children	1.44×10^{-1}	3.18×10^{-2}	8.84×10^{-4}	1.65×10^{-1}	7.27×10^{-1}
S. tuberosum	Adults	1.63×10^{-1}	3.16×10^{-2}	5.38×10^{-4}	8.34×10^{-2}	3.62×10^{-1}
	Children	7.40×10^{-2}	1.59×10^{-2}	4.05×10^{-4}	2.44×10^{-2}	1.03×10^{-1}