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Research Article

From Roots to Grains: Translocation of Heavy Metals and Associated Health Risks in Maize Grown in Dir-Kohistan, Pakistan

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ABSTRACT

Contamination of crops with heavy metals (HMs) is the most alarming environmental issue in today's world. The accumulation and consumption of HMs through the food chain and other ways can lead to serious health problems. In this context, the present study investigates the translocation of HMs, as well as the health risk assessment using maize plants (*Zea mays L.*) as a model crop. The quantity of HMs in different parts of the maize plants was measured by using atomic absorption spectrometry (AAS) and human health risk assessment was calculated for consumption of edible parts of the maize plants. The data indicated variable translocation of HMs from roots to grains in the selected model crop. The majority of HMs data determined dominancy in term of translocation from stem to leaves instead of other parts translocation factors. The distribution pattern of HMs transformation modelling from highest to lowest values in root to stem (Zn > Co > Cd > Ni > Cr > Pb > Cu > Mn), stem to leaves (Mn > Cr > Pb > Cu > Co > Zn > Cd > Ni) and stem to grains (Zn > Mn > Co > Cu > Cr > Ni > Cd > Pb) were recorded. Likewise, most of the heavy metals were found higher in roots as compared to other parts of the maize plant. In human health risk assessment, the estimated daily intake (EDI) indicated toxicity for Cd as its value was found higher than the provisional maximum tolerable daily intake (PMTDI) while rest of the elements were found in the safe limit of daily intakes. Moreover, the target hazard quotient (THQ) and total target hazard quotient (TTHQ) calculation of heavy metals in maize grains determined potential risks to the exposed inhabitants of the study area.

Keywords: Heavy metals, Maize, food safety, translocation, health risk assessment, estimated daily intake

INTRODUCTION

Heavy metals have higher density (> 5 g/cm^3), greater atomic weight (> 65), and are toxic in nature. These are found in different environmental medium in trace amounts. Some of these elements such as Fe, Zn, Mn, Cu and Cr are important in limited amount for the human health and are playing a pivotal role in the performance of various metabolic activities in human body (Mitra *et al.*, 2022; Chen *et al.*, 2024). Moreover, other metals such as Pb, Hg, As, Cd, Se etc. are considered hazardous and toxic to the human health (Ondrasek *et al.*, 2022; Ondrasek *et al.*, 2025). There are number of natural and anthropogenic sources which induce and increase the concentrations of HMs in various environmental medium. The natural sources of contamination of HMs are the weathering and erosion of various types of rocks and ores in the earth crust while the anthropogenic sources of contamination are mining, smelting, solid wastes, agrochemicals, industries, municipal/industrial wastewater, landfills, agricultural activities, sewage sludge and urbanization (He *et al.*, 2005; Gautam *et al.*, 2016; Christophoridis *et al.*, 2019; Briffa *et al.*, 2020; Subasinghe *et al.*, 2022; Deng *et al.*, 2022; Xu *et al.*, 2024). The contamination of food chain with heavy metals attracted the scientist and researchers world-wide.

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The toxicity of plants with HMs mostly subjected to the polluted soil where they are grown and settled. Heavy metals are persistent, non-biodegradable, and toxic for plants, animals and human being. The phytotoxicity with HMs indicated severe threat to the human life (Sheng *et al.*, 2022; Hu *et al.*, 2020; Li *et al.*, 2020; Kim *et al.*, 2020; Mao *et al.*, 2019). Human being and other organisms use various species of plants as a food to obtain their needs for life activities. However, the toxicity of consumable plant species causes numerous kinds of health issues such as gastrointestinal disorder, neurological problems, impaired psychological behaviour, fatal growth retardation, kidney dysfunction, cardiovascular diseases and damage of proteins and lipids (Zeng *et al.*, 2019; Filippini *et al.*, 2022; Chen *et al.*, 2024).

Heavy metals enter from soil to different part of plant species and accumulate for long time in their bodies. About 90 % of environmental contamination is generally attributed to a soil which is considered as a source and sink for pollutants (Hu *et al.*, 2020; Li *et al.*, 2020; Ersoy, 2021; Liu *et al.*, 2025). The HMs are also entering into the human body via dermal contact, inhalation and ingestion. Generally, adults and especially the children are more exposed to the toxic metals from soil (Wen *et al.*, 2019; Wang *et al.*, 2022; Laoye *et al.*, 2025).

Maize is ranked as the third most important crop in Pakistan after wheat and rice. It serves as food for humans, feed for poultry and livestock. It also contributes significantly to food security and agribusiness value. Khyber Pakhtunkhwa accounts for 57 % of the total area and 68 % of the total production of maize (Riaz *et al.*, 2014). Thus, the main objective of this study is to investigate the capacity of maize plants to absorb and translocate HMs in different upper parts in varying proportion. Considering the widespread cultivation and consumption of maize, plants from Dir-Kohistan area were selected to determine bioaccumulation of HMs in their tissues and to evaluate potential health risks posed to the local population through dietary exposure.

MATRIALS AND METHODS

Plant sampling

Field work was conducted for the collection of maize plant samples from different locations of the study area. The systematic and random sampling strategy was adopted during collection of samples from the agriculture lands of the study area. During field work 45 samples of different parts of the model crop were collected and were packed in specific zip lock bags. All the zip lock bags were properly coded with reference to the plant samples ID and code and were transferred to the geochemistry lab of the NCE in Geology, University of Peshawar for experimental work.

Plant samples preparation for chemical analysis

The collected samples were rinsed and air-dried carefully at room temperature; all the plants were cut in four parts such as roots, stems, leaves and grains and were treated separately by with following procedure:

Samples’ crushing and grinding:

The air-dried various parts of the plant samples were crushed and ground with auto-crusher mixer and were packed in small size of zip lock. All samples were protected from humidity and moisture before further processing.

Samples’ digestion:

One gram each of grains, leaves, stems and roots of maize plants were weighed through analytical balance and transferred to the vessels of the CEM automated digestion microwave system (MARS 6) which was fitted in the fuming hood. About 10 ml of nitric acid was added to each vessel and it was tightly closed. After addition of acid to the samples, a batch of twenty vessels was transferred into CEM digestion microwave and all the samples were digested in batches at a temperature of 300^0C for 15-25 minutes. After the digestion process was completed, all the samples were filtered into 50 ml of volumetric flasks and each flask was diluted to up to the mark with double deionized waters (Mahlungulu *et al.*, 2023; Chinnannan *et al.*, 2023).

Quality assurance and quality control:

For the quality assurance and quality control (QA/QC) blank samples and distilled water treated with nitric acid were also processed in the CEM automated microwave digestion system alongside the plant samples to minimize potential analytical error. Similarly, standard solutions of varying concentrations were prepared and analysed to monitor and control instrumental errors during the analysis.

Heavy metals determination

The quantitative determination of Cu, Pb, Zn, Cr, Ni, Mn and Co in the digested samples of roots, stems, leaves and using a Perkin Elmer **700** graphite furnace atomic absorption spectrophotometer (AAS) under the standard conditions by using the certified standards. The results obtained were within a 95% confidence limit.

Statistical Analysis

Statistical analysis such as descriptive statistics and analysis of variance (ANOVA) was calculated using Origin and SPSS software’s.

Potentially toxic and HMs translocation factor analysis

The translocation factor analysis of potentially toxic and HMs was also performed to know that how much of their concentration transfer from roots to various parts of the maize plants of the study area. The translocation factor of metals was obtained by using the following calculation methods:

Heavy metals translocation modelling

The heavy metals translocation modelling (HMTM) of potentially toxic and HMs was obtained by using the following equations.

$$HMTM = \frac{Mc\ in\ Stem}{Mc\ in\ Root} \qquad (1)$$

$$HMTM = \frac{Mc\ in\ Leaves}{Mc\ in\ Stem} \qquad (2)$$

$$HMTM = \frac{Mc\ in\ Grain}{Mc\ in\ Stem} \qquad (3)$$

Where HMTM stand for heavy metals translocation modelling modified after Dimitrijevic *et al.* (2016) while Mc stand for metal concentration. The metals concentration quantified in the upper parts of the plants were divided on the concentrations measured in the lower parts of the plants.

Human Health Risk Assessment

Human health risk assessment (HHRA) of HMs was calculated through feeding of the grains of maize plants in the form of Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Hazard Risk Index (HRI) or Total Target Hazard Quotient (TTHQ) as used by numerous researchers worldwide (Orisakwe *et al.*, 2012; Zhuang *et al.*, 2014; Mahfuza *et al.*, 2017; Kohzadi *et al.*, 2018; Chowdhury *et al.*, 2024).

Estimated Daily Intake

Estimated daily intake represents the amount of metals that a person daily takes through ingestion of various food materials such as grain, vegetables, flour and fruits. The below equations was used for the calculation of EDI.

$$EDI = \frac{Mc\ \times IR}{BW} \qquad (4)$$

Where the EDI stand for estimated daily intake of a metal, Mc indicates amount of metals in plant (mg/Kg), IR determines ingestion rate of edible parts of plant and BW represents the average body weight of a person. The IR and BW were considered as 0.345 kg/person/day and 70 Kg, respectively (Wang and Yang, 1996; Wang *et al.*, 2005; Orisakwe *et al.*, 2012; US EPA, 1990).

Target Hazard Quotient

The calculation of THQ is elaborated by US EPA (2000) and the following equation was used for its determination (Wang *et al.*, 2005; Kohzadi *et al.*, 2018).

$$THQ = \frac{Mc\ \times EF\ \times ED\ \times IR}{RfD\ \times BW\ \times AT} \qquad (5)$$

Where the abbreviations Mc= metals concentration in grain, EF= exposure frequency (365 days/year), ED= exposure duration (65 years for Pakistan), IR= ingestion rate (g/person/day), RfD= oral reference dose (mg/kg/day), BW= average body weight (70 Kg) and AT represents average exposure time (365 days/year × number of exposures in 65years i.e., 23725 days/years).

If THQ values for any toxic metal was found less than 1 than there will be exist no risk and if it was observed as THQ > 1than an adverse health affect may be faced by the exposed population (Chowdhury *et al.*, 2024). The oral reference dose (RfDo) for Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn are 5.0×10^{-4}, 0.03, 3.0×10^{-3}, 4.0×10^{-2},1.40E-01, 2.0×10^{-2}, 3.5×10^{-3}, and 0.3, respectively (US EPA, 2011; Finley *et al.*, 2012; Onyele and Anyanwu, 2018; Kohzadi et a., 2018; Sultana *et al.*, 2022).

Total Target Hazard Quotient

The total target hazard quotient is the summation of target hazard quotient of different HMs as a whole which has been calculated by adopting the following equation.

$$TTHQ = \sum THQ \qquad (6)$$

If the calculated amount of TTHQ is recorded below than 1 than the residents shall be safe and if it is greater than one than health risk may be faced by the consumers.

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RESULTS

Heavy metals in different parts of maize plants

The concentrations of different metals in various parts (i.e., roots, stems, leaves and grains) of the Maize plants are presented in Table 1 and Figure 1. The mean value (mg/Kg) was found as Cu in roots = 36.469, in stems =21.573, in leaves =24.429 and in grains =23.186, Zn in roots =27.231, in stems =30.745, in leaves =30.529 and in grains =43.729, Pb in roots =49.522, in stems =32.327, in leaves =37.343 and in grains =24.343, Ni in roots =45.085, in stems =39.873, in leaves =32.707 and in grains =36.857, Mn in roots =94.964, in stems =34.527, in leaves =77.964 and in grains =39.114, Cd in roots =20.166, in stems =17.955, in leaves =17.636 and in grains =15.314, Cr in roots =37.205, in stems =25.536, in leaves =38.486 and in grains =23.771 and Co in roots =40.104, in stems =44.155, in leaves =49.750 and in grains =49.571. The safe limits for HMs as threshold values of FAO/WHO (2011) and phytotoxic range for the plants were given in Table 2 to which the mean concentrations of HMs in different parts of the maize plants were compared for the purpose of elaborating the metal toxicity to maize plants and health risk to human being.

Table 1. Heavy metals measured concentration (mg/Kg) in different fragments of Maize Plants of Dir Kohistan, Pakistan.

	Root			**Stem**			**Leaves**			**Grain**		
Element	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Cu	16.4	96.6	36.469	9.9	39.4	21.573	11	40.9	24.429	13.4	33.1	23.186
Zn	12.333	66.1	27.231	10.2	68.5	30.745	3.5	86.5	30.529	13	125.2	43.729
Pb	6.2	163.258	49.522	12.7	71.5	32.327	3.6	64.8	37.343	0.7	54.2	24.343
Ni	2.3	132.667	45.085	15.4	113.4	39.873	5.6	69.3	32.707	8.1	58.4	36.857
Mn	26.6	351.8	94.964	6.3	74.3	34.527	4.9	289.5	77.964	16.7	60.4	39.114
Cd	0.2	42.7	20.166	0.8	30.2	17.955	0.2	34.7	17.636	0.2	34.7	15.314
Cr	5.2	112.495	37.205	3.7	49.3	25.536	4.9	144.7	38.486	15	36	23.771
Co	4.091	115.167	40.104	2.2	70.9	44.155	13.6	83	49.750	2.5	92.7	49.571

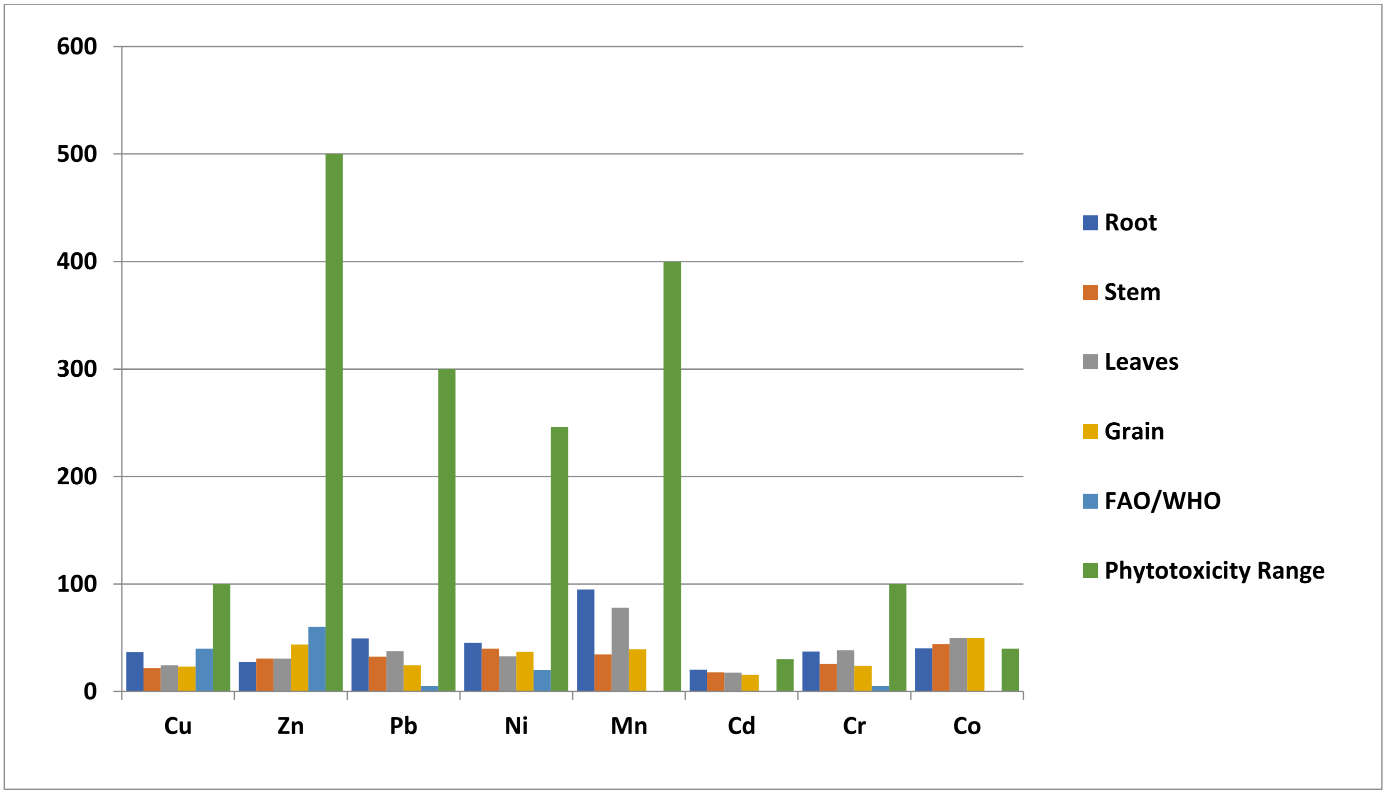

Figure 1. Comparison of heavy metals (mg/Kg) in different parts of the Maize plants and with FAO/WHO safe limits and phytotoxicity range.

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Table 2. Heavy metals FAO/WHO safe limit and phytotoxic range (mg/Kg) in plants.

Element	FAO/WHO Safe Limit	Phytotoxic Range
Cu	40	20-100
Zn	60	100-500
Pb	5	30-300
Ni	20	40-246
Mn	-	> 400
Cd	0.3	5.0-30
Cr	5	10-100
Co	-	30-40

Table 3. Analysis of variance (ANOVA) for heavy metals in various parts of the maize plants.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups (parts)	885.433	3	295.144	1.092	0.369	2.947
Within Groups	7569.529	28	270.340			
Total	8454.962	31				

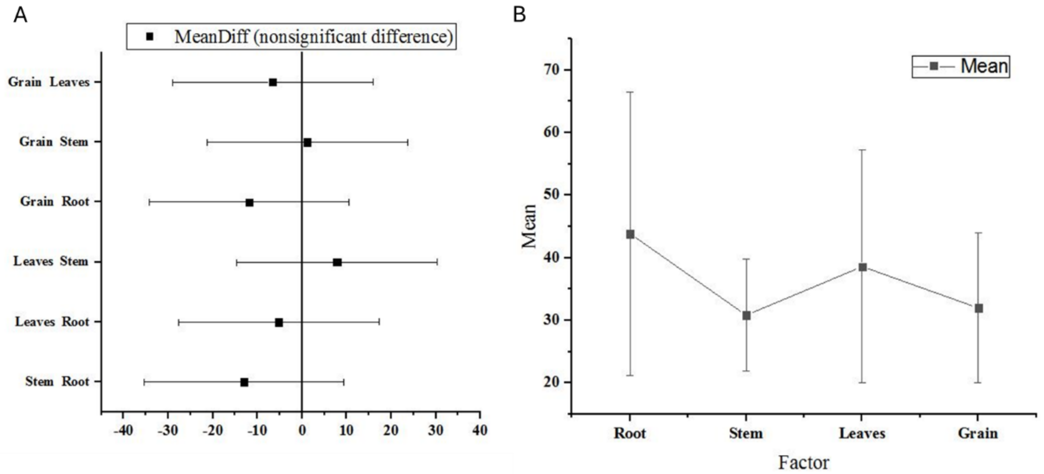

Figure 2. (A) Mean differences within multiple groups with post-hoc test (Tukey's test), (B) Mean comparison among different parts of the maize plants

The statistical analysis such as ANOVA (Table 3) and post-hoc test (Tukey's test) (Fig. 2 a) for comparison were performed. The summary in term of sum, mean and variance for different part of the maize plants for all elements was obtained. The mean ±SD values for root, stem, leaves and grains were obtained as 43.843 ±22.666, 30.836 ±8.902, 38.605 ±18.577 and 31.986 ±11.970, respectively along with standard deviation error (Fig. 2 b). The ANOVA indicated source of variation between groups and within groups. The sum of square (SS), degree of freedom (df), mean square (MS), F test, P-value and F critical test between groups were obtained as of 885.433, 3, 295.144, 1.092, 0.369 and 2.947. Likewise, source of variation within groups for SS, df and MS was obtained as of 7569.529, 28 and 270.340, respectively. The mean difference (non-significant difference) between pairs of plant parts of Tukey's test indicated with X-axis as vertical line at 0 determined no difference. Likewise, Y-axis indicated pairwise comparison between two different parts of the maize plants. In this study, the mean differences (Black Square in Fig. 2 (a) between two parts such as between grain-stem and leaves-stem is positive while rest of the multiple groups comparison falls negatively. The Fig. 2 (a) indicated no statistically significant differences between the different parts of the plants as all the confidence intervals (horizontal lines) crossing the vertical line at 0 which combines the legends. Moreover, the comparison of HMs in different tissues of maize plant (Fig. 2 b) indicated the highest concentrations in the roots compared to other parts of the maize plants. This elevated accumulation in roots may be attributed to the higher concentrations of HMs in the surrounding soil of the study area. Therefore, it is recommended that soil contamination be studied alongside plant tissue analysis to provide a clear understanding of the contamination profile and its potential impacts.

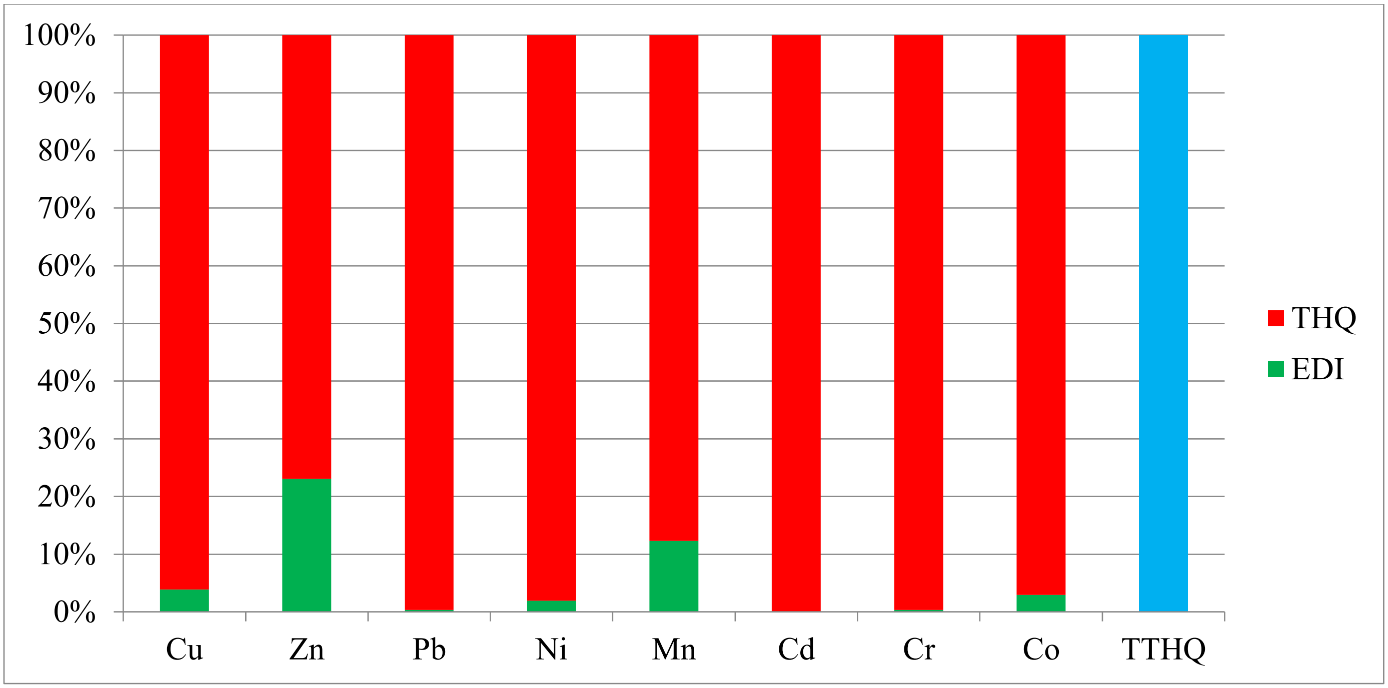

Figure 3. Estimated daily intake (EDI), target hazard quotient (THQ) and total target hazard quotient (TTHQ) of HMs in edible part of maize plant

Table 4. Heavy metals translocation modeling in various parts of the Maize Plants.

Element	**Root to Stem**	**Stem to Leaves**	**Stem to grains**
Cu	0.592	1.132	1.075
Zn	1.129	0.993	1.422
Pb	0.653	1.155	0.753
Ni	0.884	0.820	0.924
Mn	0.364	2.258	1.133
Cd	0.890	0.982	0.853
Cr	0.686	1.507	0.931
Co	1.101	1.127	1.123

Heavy metals translocation from root to stem, stem to leaves and stem to grains were calculated by using the HMTM equations 1, 2 and 3, respectively and the results were given in Table 4. The results of Table 4 indicating translocation factor analysis data on basis of mean values of HMs measured in different parts of maize plants. The translocations of Cu (1.132), Pb (1.155), Mn (2.258), Cd (0.982), Cr (1.507) and Co (1.127) were found higher from stem to leaves while of Zn (1.422) and Ni (0.924) translocations were found higher from stem to grains instead of other parts of the plants (Table 4). The data indicated that translocation of most of the elements were found higher in stem to leaves except of Zn and Ni, both of which found higher in stem to grains translocation.

Human health risk assessment was obtained in term of EDI, THQ and TTHQ by using equations 4, 5 and 6 respectively and graphically illustrated in Figure 3. The EDI for HMs such as Cu, Co, Zn, Mn, Pb, Ni, Cd and Cr was found as 0.114, 0.244, 0.216, 0.193, 0.120, 0.182, 0.075 and 0.117, respectively. The target hazard quotient calculated values were found as of 8.144, 2.857, 150.955, 0.718, 34.279, 9.083, 1.377, and 39.053 for Co, Cu, Cd, Zn, Pb, Ni, Mn and Cr, respectively. The total target hazard quotient value of all (eight) HMs was found as 246.466, exceeded the concerned threshold value of human health risk.

DISCUSSION

The results indicated higher concentrations for Ni, Cd, Pb, Cu and Mn in roots than other parts (stems, leaves and grains) of the maize plant (i.e., *Zea mays*). Moreover, the highest concentrations of Co and Cr were observed in the leaves, while the highest concentration of Zn was found in grains. A comparison of the mean values of HMs in the root, stem, leaves and grains of maize plants with the safe limit of FAO/WHO (2011) indicated no contamination for Cu and Zn. However, contamination by Pb, Ni, Cd and Cr was observed in all parts of maize plants. Furthermore, the mean concentrations of all HMs in all parts of the maize plants were within the phytotoxic ranges reported by Kabata-Pendias (2011). Additionally, the distribution order of HMs in different parts of the maize plant was found as Cu (root> leaves > grain > stem); Zn (grain > stem > leaves > root); Pb (root > leaves > stem > grain); Ni (root > stem > grain > leaves); Mn (root > leaves > grain > stem); Cd (root > stem > leaves > grain); Cr (leaves > root > stem > grain) and Co (leaves > grain > stem > root). It was observed the majority of HMs were concentrated in the roots of the maize plants in the study area. This finding is consistent with the observations of Nouri *et al.* (2009), Islam *et al.* (2024) and Rahman *et al.* (2024). This can be attributed to the adsorption of HMs from the soil through roots, followed by their selective translocation to the aerial parts of the plant. Maize plants are used as fodder for animals, and their grains are consumed as food for humans. The contamination of Maize plants with HMs has attracted global attention due to potential health risks. The use of manures and agrochemicals is widespread in the study area to achieve high yields, and both are considered significant source of contamination and transformation of HMs, especially Zn, Cu and Pb, which accumulate in the upper parts of the plants, particularly in the grains (Zakir *et al.*, 2011). The primary source of HMs is the soil, from which they are bioaccumulated and transferred into the food chain, ultimately posing risks to human health through consumption (Islam *et al.*, 2024). Therefore, maize plants, as the most widely consumed edible product in the study area, were selected for assessing human health risks and suggesting preventive measures to mitigate the negative effects of HMs. In the present study, the mean concentrations of Pb, Ni, Cd and Cr in root, stem, leaves and grains of maize plants exceeded the safe standard limits established by FAO/WHO (2011), representing serious threats to the residents of the study area. The primary sources of HMs in the environment are geogenic processes, urbanization, and industrialization, which contribute to the release of these metals, leading to health related issues (Li *et al.*, 2021). The descriptive statistical analysis, expressed as means ±SD, revealed the highest values of all HMs in the roots, with the lowest values observed in the stems. ANOVA analysis determined that F-statistic value was lowers than the F-critical value, supporting the null hypothesis. Additionally, the p-value was greater than the significant level (0.05), indicating no statistically significant differences in the measured HMs concentrations among the various tissues types of maize plants in the study area.

The translocation modelling data indicated the highest translocation of Cu from stem to leaves, Zn from stem to grains, Pb from stem to leaves, Ni from stem to grains, Mn from stem to leaves, Cd from stem to leaves, Cr from stem to leaves, and Co from stem to leaves. Most of the data showed a dominant translocation from stem to leaves over other factors. The translocation of HMs from root to stem was higher than 1 for Zn and Co; and from stem to leaves for Cu, Pb, Mn, Cr and Co. For stem to grains, the translocation was found greater for Cu, Zn, Mn and Co, with values higher than 1, suggesting the potential for pollution and toxicity in the plant body (Dimitrijevic *et al.*, 2016). The distribution pattern of HMs translocation modelling followed the sequence from highest to lowest values from root to stem: Zn > Co > Cd > Ni > Cr > Pb > Cu > Mn, from stem to leaves: Mn > Cr > Pb > Cu > Co > Zn > Cd > Ni, and from stem to grains: Zn > Mn > Co > Cu > Cr > Ni > Cd > Pb. The HMs are persistent in nature and negatively affects the growth and yield of plant. The existence of Zn accelerates the accumulation and translocation of HMs (Pb and Cd) in the upper parts of maize plants (Shafiq *et al.*, 2020). Armienta *et al.* (2020) determined the HMs accumulation order in maize plants as Zn > Fe > Pb > As > Cd. The HMs assimilation in maize plants influenced due to the concentration of contaminants and nutrients availability (Armienta *et al.* 2020). Aboveground tissues of maize plants have high accumulation capacity and could be used as a phytoremediation for Cd-contaminated soil. The transfer factor of Cd decreases in order of root > straw > grain (Wang *et al.*, 2016). The comparative studies determined that Pakistan's maize plants indicate elevated concentrations of Cr, Cd, Pb and Ni, which complies with the present study (Shah *et al.*, 2016; Awan *et al.*, 2019). Furthermore, in China, the significant level of Cr, Pb, Ni and Zn observed in food crops which comply with present study and major source of contamination was attributed to irrigation with wastewater (Liu *et al.*, 2005). In Nigeria, the elevated level of Pb, Cd and Cr observed in grains (Akenga *et al.*, 2017; Nkwunonwo *et al.*, 2020). These finding underscore the need for region-wise strategies to mitigate HMs contamination in maize and ensure food safety. There is a close relationship between plants and heavy metals and understanding of this relationship is very important. The plants primarily absorb HMs from contaminated soil and irrigation water. Elevated HMs adversely affect plant growth and yield.. For instance, Cd at concentration of 36 mg/Kg significantly reduced roots and shoots lengths by 65 % and 32 %, respectively. Likewise, Cr at 204 mg/Kg) decreased chlorophyll content by77 %, grain yield by 84%, and grain protein content by 16 % (Rizvi and Khan, 2019). Concentration data revealed significant pollution with Cd, Pb, Ni, and Cr in all parts of the maize plants. However, the concentration of Cu and Zn remained within the safe limits established by FAO/WHO (2011). Copper plays a vital role in oxidative phosphorylation and control deregulation of glucose (Fardi *et al.*, 2021; Mawari *et al.*, 2022), while Zn is essential for insulin synthesis of and diabetes regulation (Kazi *et al.*, 2014; Nakamura *et al.*, 2024). Moreover, the toxicity of maize plants with Pb, Ni, Cd and Cr is not only alarming for human being but also for animal, as maize biomass is commonly used as a fodder. Pb is potentially toxic metal, and its elevated concentration is associated with several health issues, including hypertension, children retardation, kidneys dysfunction, reproductive problems in adults and other chronic conditions (Rehman *et al.*, 2017; Kumar *et al.*, 2020). Elevated nickel levels also pose health risks such as dermatitis, cancer, respiratory problems and other allergic reaction (Das *et al.*, 2019). Furthermore, cadmium is also toxic metal and its elevated concentration led to serious health problems, including renal dysfunction, bone damage and cancer (Wang *et al.*, 2019). Chromium is an essential trace metal involved in glucose metabolism and insulin sensitivity (Sinha *et al.*, 2018). However, elevated levels of Cr can lead to several health problems such as anemia, asthma, cancer of lungs, burns, dermatitis, ulcer, damage to sperm, kidney and liver diseases (Hekhawat *et al.*, 2015; Hossini *et al.*, 2022).

The EDI values for HMs followed a descending order of: Co > Zn > Mn > Ni > Pb > Cr > Cu > Cd. The uppermost EDI in the edible part (grains) was recorded for Co, while the lowermost was found for Cd. The EDI calculated values determined health risk only for Cd when compared with provisional maximum tolerable daily intake (PMTDI) for HMs (Cu= 2.0, Mn= 5, Zn= 20, Cd= 0.046, Pb= 0.21, Ni= 0.3, and Cr= 0.2) (WHO/FAO, 2011; Rahman *et al.*, 2024). The THQ values of all HMs except of Zn were observed higher than 1, indicated health threats to the residents of the study area (Chowdhury *et al.*, 2024). The total target hazard quotient value of all (eight) HMs was found in avery high concentration, posed serious health threats to humans of the study area as its value was found higher than 1 (Chowdhury *et al.*, 2024). The highest values of TTHQ is majorly owing to Cd, Cr and Pb and of all of these metals are potentially toxic to human in very small amount (Tchounwou *et al.*, 2012; Jaishankar *et al.*, 2014); therefore, it is suggested to not consume the grains as a food for human beings of the study area.

CONCLUSION

Heavy metals pollution is the most serious threat to environment and human health. Its continuous monitoring and pollution control strategies is very necessary to mitigate the adverse effects and ensure sustainable environment. The results of the study exposed the highest absorptions of Cd, Cu, Mn, Pb and Ni in roots, Co and Cr in leaves and Zn in grains of maize plants. Furthermore, the comparative study of mean values of HMs in root, stem, leaves and grains of maize plants with safe limit of FAO/WHO (2011) indicated no contamination for Cu and Zn while contamination for Pb, Ni, Cd and Cr in all parts of maize plants. Moreover, the mean values of all HMs, in all parts of the maize plants were found within the phytotoxic range indicated no toxicity to the maize plants of the study area. The human health risk assessment calculations (i.e., EDI, THQ and TTHQ) for HMs were also calculated to identify potential threats to human population. The estimated daily intake was found highest for Co while lowest for Cd among other HMs. Moreover, the target hazard quotient and total target hazard quotient for HMs except of Zn in the edible part (grains) of maize plants determined potential risk to the exposed residents of the study area. Thus, continuous monitoring of HMS analysis in maize plants and grains is recommended to avoid any risk to the human life. The region of the present study is needed further details maize toxicity with HMs to provide baseline information for the researchers and policy makers.

AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study. Fieldwork, manuscript writing, and revision were carried out by Shafiullah, Mohammad Tahir Shah, Liaqat Ali, and Seema Anjum Khattak. The first draft of the manuscript was prepared by Shafiullah. All authors reviewed and provided input on earlier versions of the manuscript, and all have read and approved the final version.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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