Potentially toxic metals in Northeast Ethiopian agricultural soils: implications for Solanum lycopersicum (Tomato) production and human health

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ORIGINAL PAPER

Potentially toxic metals in Northeast Ethiopian agricultural soils: implications for *Solanum lycopersicum* (Tomato) production and human health

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Abstract Exposure to heavy metal-contaminated vegetables, irrigation water and agricultural soil is one of the most challenging environmental issues worldwide. This study aimed to evaluate the health effects of potentially toxic metals (PTMs) including Cr, Cd, Fe, Pb, Cu, Zn, and Co from agricultural soil, irrigation water, and tomato plants collected from the Abuarie irrigation site, Northeast Ethiopia. The samples were digested using acid digestion method, and its concentration was quantified using Inductively Coupled Plasma–Optical Emission Spectroscopy. The concentrations of PTMs in the soil, tomato, and irrigation water samples ranged from 49,020 ± 275 (Fe) to 11.85 ± 0.44 (Cd), 170 ± 1.98 (Fe) to 0.29 ± 0.006 (Cd) mg kg^{-1}, and 0.24 ± 0.003 (Fe) to 0.025 ± 0.005 (Ni) mg L^{-1} , respectively. The results revealed Zn, Ni, Cd and Cr in soil, all metals in tomato, and Cu, Ni, Cd and Pb in irrigation water sample were above the World Health Organization threshold values. Moreover, the separate and cumulative exposure to farm soil, irrigation water, and consumption of tomato were investigated using the hazard quotient (HQ) and hazard index (HI) values, respectively. The results revealed that individual exposure to each sample type did not have a significant impact on health (HQ < 1). However, simultaneous exposure to all of the sample types (soil, tomato and irrigation water) at the same time had a high likelihood of affecting health (HI > 1). The total carcinogenic concentrations of Cr, Cd, Ni, and Pb were greater than 1×10^{-4}, revealing that farmers have a high probability of developing cancer during their lifetime. Minimizing simultaneous exposure to soil, tomato, and irrigated water for local people is highly recommended to prevent the risk of PTMs.

Keywords Potential toxic metal · Tomato · Soil · Irrigation water · Health risk

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Introduction

The different environmental segments (such as soil, water and air) polluted by different contaminants come from either natural (such as rock weathering and volcanic eruption) or anthropogenic activities (including urban and industrial waste, transportation infrastructure, and the burning of fossil fuels), which pose a tremendous challenge for the world as a whole and developing countries in particular (van der Merwe, 2021). For instance, the quality and security

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of crops, vegetables, and fruits are highly influenced by PTM contaminants that come from polluted soil, water and agrochemical administration (Taiyang Zhong et al., 2018). PTMs are among the main environmental pollutants due to their persistence, toxicity, and harmful effects on ecosystems and humans (Ezez & Belew, 2023). PTMs can enter the body through dietary intake and nondietary intake (Mirzaei Aminiyan et al., 2018; Moghtaderi et al., 2019). Among the exposure routes of PTMs, oral intake/ingestion through the consumption of foods contaminated with heavy metals contributes up to 90% of exposure, and regular consumption of HM-polluted food products tends to increase the levels of PTMs in the body (Al-Sudani et al., 2021; Du et al., 2013). The increase and accumulation of PTMs in the body results in various illnesses, such as liver and kidney failure, lung tissue damage, respiratory disorders, and cancer (Dunage et al., 2010).

The agricultural sector is the backbone of the country's economy, supporting the livelihoods of the majority of its population. It is the major supplier of raw materials to the food processing, beverage, and textile industries. It accounts for more than 85% of the labor force and 90% of the export earnings (Aregu et al., 2018; Endale, 2011). However, the widespread use of agrochemicals such as pesticides, herbicides, and organic and inorganic fertilizers in the agricultural sector is the primary cause of PTM pollution in soil, particularly in emerging countries (van der Merwe, 2021). Fruit and vegetables cultivated in polluted soil, water, and air can absorb and accumulate enormous amounts of PTMs in various plant parts, which can lead to increased PTMs in food chains (Arumugam et al., 2021; Dong et al., 2020; Li et al., 2017). The content of PTMs in plants mainly depends on the plant species, soil characteristics, physicochemical properties of water, and weather conditions in which the plant is grown (German & Walzem, 2000; Mirecki et al., 2015).

Tomato is one of the staple vegetable crops farmed in Ethiopia by smallholder farmers, commercial states, and private farms in both the rainy and dry seasons. This crop is also a significant component of Ethiopian diets (Emana et al., 2017). Among the areas used for producing vegetables and crops, Abuarie farmland is the prospective farmland in the Kobo area and has been used for growing various kinds of fruits and vegetables via irrigation water (Bayissa & Gebeyehu, 2021; Zhong et al., 2018). Farmers in the region frequently use fertilizers (e.g., phosphate and nitrogen) and pesticides (e.g., insecticides and herbicides) to boost crop output and economic growth. However, the information obtained from the local farmer and the preliminary field observation in study area confirmed inappropriate application of pesticides, herbicides, and fertilizers, which can contaminate agricultural soil and irrigation water with PTMs, and crops cultivated in these areas are highly susceptible to PTM contamination. Farmland is located at the foot of the surrounding plateau, and rock weathering and erosion of soil from the plateau areas also increase the pollution of farmland by PTMs. The main road near the farmland that connects the Amhara and Tgray regional states, where a large number of transport vehicles travel per day, might be another main source of PTMs (Aminiyan et al., 2022; Moghtaderi et al., 2019). Moreover, poor domestic waste management in the surrounding towns and villages may also contribute an enormous amount of PTMs to the farmland. As a result of the persistent nature of PTMs, they can accumulate over time in soil and irrigation water and can be passed from plants to people via the food chain. The consumption of tomatoes (one of the most predominant agricultural products on farmland) and exposure to irrigated water and soil might pose a variety of health hazards to the inhabitants. Additionally, there has yet to be any research on the amount of PTMs in this area's soil, tomatoes, or irrigation water. Consequently, assessing the level of PTMs in tomato and agricultural soils, as well as irrigation water and estimating the possible cancer and noncancer risk of the inhabitants are crucial steps in remedial action. The findings also provide baseline information for national policymakers to develop or amend the existing guidelines (Ezez & Belew, 2023). Therefore, the main goal of the present study was to quantify the concentrations of selected PTMs in soil, irrigation water, and tomato (*Solanum lycopersicum*) and estimate their associated health hazards.

Materials and methods

Study area description

This study was conducted around Ray Kobo in Northeast Ethiopia. It is 60 km from Woldia, the administrative district of Kobo or Raya Kobo. The study area has a mean annual rainfall and temperature ranging from 500 to 850 mm and from 19 to 33 °C, respectively. Its elevation varies from 1100 to 3000 m above sea level with coordinates of 12004′ 29.75″ N and 39040′ 05.40″ E (Abebe, 2020). The sampling site is presented in Fig. 1.

Collection and preparation of soil, tomato, and irrigation water samples

Soil sample collection

The top 0–30 cm of the soil layer was considered, as most of the soil's chemical interactions with the atmosphere are expected to occur (Kumar et al., 2019). Thus, the soil sample was collected from each of the three subsampling points using a soil stainless steel auger, and then the collected samples were mixed to form 3 kg of the composite bulk sample. Approximately 1 kg of soil sample was taken from a bulk sample, labeled, packed, brought to the laboratory, and then dried at room temperature for three weeks. The samples were then ground with a mortar and pestle to pass through a 1 mm sieve and homogenized. Finally, the sieved soil samples were stored in polyethylene bags, and stored in desiccators until digestion.

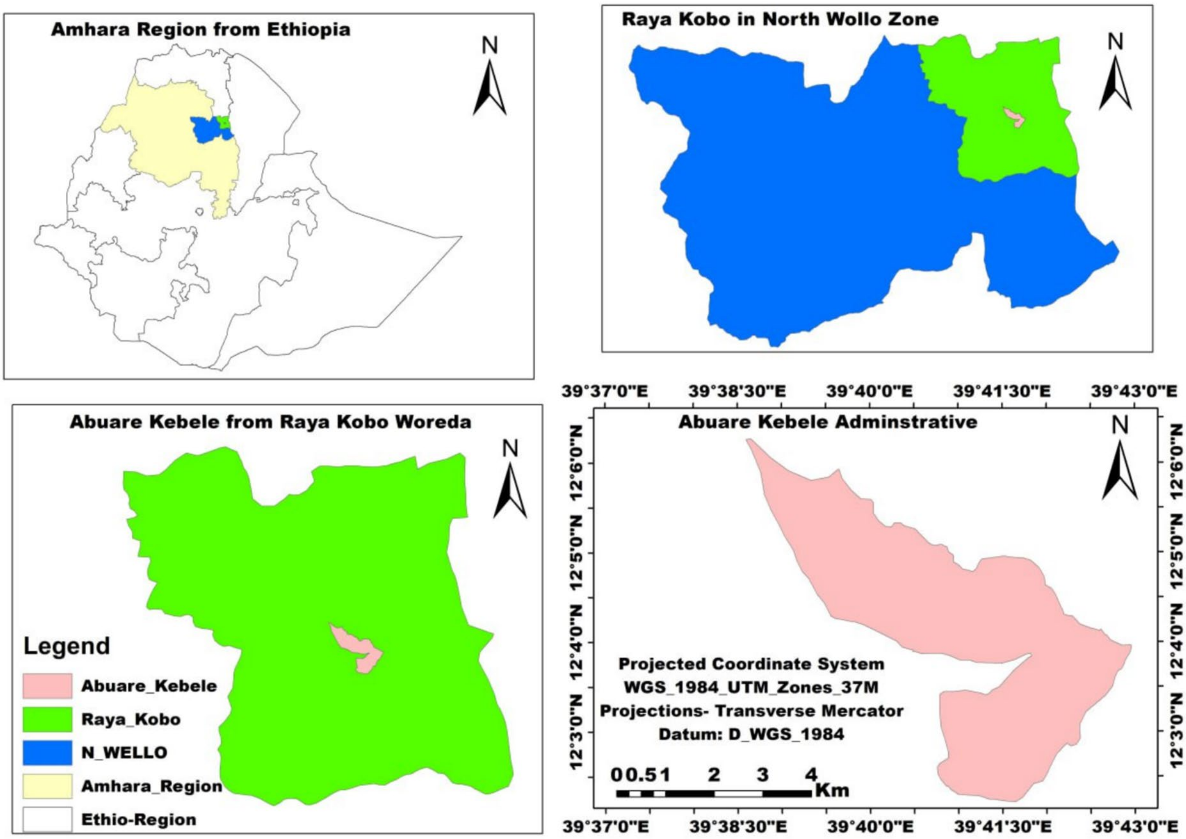

Fig. 1 Geographical location of Abuarie farmland, Ethiopia

Tomato sample collection

One kilogram of tomato sample was taken from the composite 3 kg of tomato sample from which the soil sample was taken. Then, the tomato sample was carefully cut and chopped before being properly mixed with tap water to remove any remaining dust. The collected samples were then brought to a laboratory for additional processing. The collected tomato samples were properly cleaned in the laboratory before being further chopped and diced into smaller pieces to allow drying. Then, the samples were air-dried for five to six days in a hot oven for 24 h at 55 °C, ground and sieved through a 1 mm mesh (Deribachew et al., 2015). Finally, the sieved samples were stored in polyethylene bags, which were then kept in desiccators until digestion.

Irrigation water sample collection

Approximately 500 mL water samples from the Golina River, which are used for irrigation purposes, were collected from 3 different sites (upper stream, middle steam, and lower stream), and 1500 mL composite samples were collected. Then, 250 mL water samples were collected with clean and dry polyethylene. The collected water sample was acidified with 1 mL nitric acid to prevent microbial degradation of heavy metals in the solution. Finally, the sample was brought to the laboratory and kept in a refrigerator until digestion.

Digestion of soil, tomato, and irrigation water samples

Digestion of soil samples

A total of 1.25 g of dried and powdered soil was digested with 20 mL of aqua regia (HCl/HNO_3 3:1) in a beaker (open-beaker digestion) on a hot plate. The digested samples were heated to near dryness and cooled to ambient temperature (Güven & Akinci, 2011). Then, 5.0 mL of hydrogen peroxide was added to the parts to complete the digestion, and the resulting mixture was heated again to near dryness in a fume hood. The beaker walls were washed with 10 mL of deionized water, 5 mL of HCl was added, and the mixture was heated again. The resulting digest was allowed to cool, put into a 50 mL volumetric flask, and filled to the mark with deionized water (Mutegoa et al., 2021).

Digestion of tomato samples

A 0.5 g homogenized powdered tomato sample was introduced from the desiccator into a borosilicate-digested flask. Then, 10 mL of an acid-mixed solution containing HNO_3: HCl: H_2O_2 at a ratio of 8:1:1 (v/v/v) was added, and the mixture was heated at 120 °C for three hours on a block digester. Next, the digested solution was filtered into 100 mL volumetric flasks using Whatman filter paper (Cárdenas-Castro et al., 2021). Finally, the cooled solution was filled with deionized water. All the solutions of the target analyte of the sample were stored in the refrigerator until analysis.

Digestion of irrigation water

The irrigation water sample bottles were shaken thoroughly by hand, and then 100 mL of the sample and 5 mL of concentrated nitric acid were mixed and placed in a conical flask. Second, the mixture was heated slowly below 180 °C for two hours on a hot plate and evaporated to approximately 20 mL, ensuring that the water did not boil. Then, heating was continued after adding 5 ml of fresh, concentrated nitric acid by covering the beaker with a watch glass. Third, 2 mL of concentrated hydrochloric acid was heated slightly to dissolve any remaining residue. Fourth, a few drops of hydrogen peroxide were added to ensure that complete digestion had occurred. Finally, the solution was filtered using Whatman filter paper, and the filtrate was transferred to a 100 mL volumetric flask to cool and fill with deionized water until the mark of the flask was reached (Patil et al., 2012).

After the digestion of the soil, the tomato plants and irrigation water were subjected to PTM quantification via ICP−OES.

Method validation and calibration of ICP−OES data

Method validation

The analytical method used for the study was carried out using the method detection limit (MDL), limit of quantification (LOQ), and spiked recovery test (Dagne et al., 2019). Thus, the three replicate blank samples were digested using the same processes as the soil, tomato, and irrigation water samples for estimation of the MDL and LOQ using formulas (1) and (2), respectively.

$$\mathrm{MDL} = 3 \times \mathrm{SD} \tag{1}$$

$$\mathrm{LOQ} = 10 \times \mathrm{SD} \tag{2}$$

where SD = standard deviation of the blank.

Recovery test

The accuracy of the analytical method was confirmed by a recovery test. Thus, a small and known amount of heavy metals from the stock solution was added or spiked into the soil, tomato, and irrigation water samples to be digested in the same way as the sample. The concentrations of both spiked and non-spiked samples were read to test the effectiveness of the analytical process. The percentage recoveries of the analytes were determined through Eq. (3) (Dagne et al., 2019).

$$\%\mathrm{Recovery} = \left(\frac{\mathrm{CM\ in\ the\ spik\ sample} - \mathrm{CM\ in\ the\ non\text{-}spike\ sample}}{\mathrm{Amount\ added}}\right) \times 100 \tag{3}$$

where CM = the concentration of the metal of interest.

Calibration of the ICP–OES

A series of calibration standard solutions for each metal was prepared by dilution with 0.5% nitric acid from the standard stock solutions, which was 1000 ppm in 3% nitric acid. Thus, all standard solutions were prepared in 50 ml volumetric flasks, and the serial dilutions for each metal are given in Supplementary Table 3.

Transfer factor (TF)

The transfer factor (TF), which is frequently used in the scientific literature as a metric for the biotransfer of heavy metals, is the ratio of the concentration of a heavy metal in a plant to the concentration of a heavy metal in soil. The heavy metal content of the soil that reached the tomato plants is indicated by the letter TF. TF is calculated to determine the degree of risk and related hazard due to ingestion due to heavy metal buildup in the edible portion of tomato vegetables (Mirecki et al., 2015; Taye & Chandravanshi, 2023).

$$\mathrm{TF} = \frac{C_{tomato}}{C_{soil}} \tag{4}$$

where TF is the transfer factor, C_{tomato} is the metal content in tomato (mg kg^{-1}), and C_{soil} is the metal content in soil (mg kg^{-1}).

Health risk assessment

The PTM health risks due to the consumption of tomatoes, intake of irrigation water, and agricultural soil were assessed based on the average daily chorionic dose (ADD), health risk index (HI), and hazard quotient (HQ) (Khan et al., 2008; Wan et al., 2022).

Average daily dose (ADD)

People may be exposed to PTMs from the soil through various routes, including dermal contact, inhalation, and oral absorption of soil particles. These plants are also exposed to PTMs by consuming tomatoes and irrigation water. The estimated PTM intake from soil was expressed as the average daily dose of inhalation, dermal exposure, and ingestion using Eqs. (5)–(7), while Eqs. (8) and (9) were used to evaluate the ADD of PTMs by tomato consumption and irrigation water, respectively (Song et al., 2015).

$$\mathrm{ADD}_{oral} = \frac{C_s \times \mathrm{IngR} \times \mathrm{CF} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \tag{5}$$

$$\mathrm{ADD}_{inh} = \frac{C_s \times \mathrm{InhR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT} \times \mathrm{PEF}} \tag{6}$$

$$ADD_{derm} = \frac{C_s \times SL \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (7)$$

$$ADD_{tom} = \frac{C_t \times IngR \times CF \times EF \times ED}{BW \times AT} \times 10^{-3} \quad (8)$$

$$ADD_{wat} = \frac{C_w \times IngR \times EF \times ED}{BW \times AT} \quad (9)$$

where C_s and C_t are the heavy metal (HM) concentrations (mg kg^{-1}) in the soil, tomato, and irrigation water, respectively, and CF is the conversion factor used to convert fresh vegetable weight to dry weight (Song et al., 2015). ADD_{oral}, ADD_{inh}, and ADD_{derm} are the average daily doses taken by oral intake, inhalation, and dermal contact of soil dust (in mg kg^{-1} day^{-1}), respectively; ADD_{wat} ADD_{tom} is the estimated average daily dose intake PTMs through irrigation water (mg L^{-1} day^{-1}) and tomato (mg kg^{-1} day^{-1}); and C_w is the PTM concentration of the irrigation water (mg L^{-1}). The interpretation and the values of the IngR, InhR, SL, EF, ED, AT, BW, PEF, SA, AF, and ABS parameters in Eqs. (5)–(9) are described in Table 1. The values are obtained from the United States Environmental Protection Agency (USEPA) and a previous report, unless otherwise indicated (Sultana et al., 2017).

Noncarcinogenic risk assessment

Hazard quotient (HQ) and health risk index (HI) parameters were employed for estimating the noncancer risk. The hazard quotient is the ratio of the toxic element's average daily exposure dose to its specific reference dose, whereas the sum of the individual HQs is called the HI. A severe health risk to humans exists when the HQ or HI is greater than one, whereas there are no serious adverse effects on human health when the HQ or HI is less than one. Equation (10) was used to determine the HQ, which is used to estimate the risk of a particular HM, while Eq. (11) was used for quantifying the HI, which is used to estimate the cumulative effect of PTMs being assessed.

$$HQ = \frac{ADD}{RfD} \quad (10)$$

$$HI = \sum_{K=1}^{n} HQ \quad (11)$$

where ADD is the average daily dose of PTM intake in mg day^{-1} kg^{-1} body weight and RfD is the reference dose (mg kg^{-1} day^{-1}) for each metal, as presented in Table 2 (Mohammadi et al., 2019):

Table 1 Interpretation and values and units of the parameters for the estimation of human exposure (Abebe et al., 2023; Ezez & Belew, 2023; Mohamed et al., 2020; Mohammed et al., 2023; Shafiuddin Ahmed et al., 2021; Wang et al., 2012; Zheng et al., 2020)

Parameters		Unit	Value
IngR	Ingestion rate (soil)	mg day^{-1}	30
	Tomato	mg day^{-1}	325
	Water	L day^{-1}	2
InhR	Inhalation rate	m^3 day^{-1}	7.6
ABS	Skin absorption factor	Unit less	0.001
AF	Adhesive factor	mg cm^{-2} day^{-1}	0.07
BW	Body weight	kg	65
SL	Skin adherence factor	Mg cm^{-2} day^{-1}	0.07
ED	Exposure duration	Year	40
EF	Exposure frequency	day $year^{-1}$	300
PEF	Particular emission factor	m^3kg^{-1}	1.36×10^9
SA	Skin area	cm^2	5700
CF	Conversion factor	Unit less	0.085
AT	Average time	days	For cancer, 70×365
			For noncancer $ED \times 365$

The average body weight for an Ethiopian adult is 65 kg

Table 2 RfD and CSF values of heavy metals for different sample types and exposure routes (Taye & Chandravanshi, 2023; Zheng et al., 2020)

PTMs	RfD for soil			RfD for tomato	CF for soil and water		
	RfD_{Inh}	RfD_{Der}	RfD_{oral}	RfD_{Ing}	CSF_{Der}	CSF_{Inh}	CSF_{Ing}
Fe	0.00022	0.07	0.84	0.7			
Zn	0.3	0.06	0.3	0.3			
Cu	0.04	0.012	0.04	0.04			
Pb	0.00352	0.000525	0.0035	0.0035	0.0085	0.00008	0.085
Cr		0.00005	0.003	0.003	0.0065	0.012	42
Cd	0.001	0.00001	0.001	0.001	6.3	0.0018	6.3
Ni	0.0206	0.0054	0.02	0.02	0.84	0.00024	0.84
Co		0.016	0.02	0.0003			

The RfD for the water sample is 0.06 mg kg^{-1} day^{-1}

Carcinogenic risk assessment

The carcinogenic analysis is realized by evaluating the probable cancer risks due to exposure to heavy metals by calculating the cancer risk (CR) through Eq. (12). The CR is the incremental probability of a person developing any cancer over a lifetime due to 24 h of per-day exposure to a given daily amount of a carcinogenic element for 70 years. A CR for one or more heavy metals below 10^{-6} is an acceptable value at which the likelihood of developing cancer is relatively low. A CR greater than 10^{-4} indicates that the cancer risk affects human health; if the CR is between 10^{-4} and 10^{-6}, it is tolerable (Ullah et al., 2022).

$$CR = ADD \times CSF \tag{12}$$

$$TCR = \sum CR \tag{13}$$

where CR = cancer risk over a lifetime by individual heavy metal ingestion, TCR = total cancer risk due to multiple elements, CSF = cancer slope factor (mg kg^{-1} day^{-1}) for each exposure route (presented in Table 3), and ADD = average daily dose (mg kg^{-1}) or (mg L^{-1} for water) (Taye & Chandravanshi, 2023; Zheng et al., 2020).

Data analysis

SPSS software version 26 was used for the statistical analysis, including Pearson correlation and ANOVA (analysis of variance). The amounts of PTMs were expressed as the mean ± standard deviation (SD) in the soil, tomato, and water samples. Descriptive statistics can be employed to obtain the mean PTMs in water, tomato, and soil samples. ANOVA was used to assess the significant differences among the samples. A 95% confidence level was chosen for all significance tests unless otherwise indicated.

Table 3 Concentrations of selected heavy metals in soil, tomato, and irrigation water samples with the recommended values (Atta et al., 2022; Chaoua et al., 2019; Dagne et al., 2019)

PTMs	Soil sample in mg kg^{-1}			Tomato sample in mg kg^{-1}			Water sample in mg L^{-1}		
	Mean	WHO/FAO	USEPA 2012	Mean	WHO	USEPA2012	Mean	WHO/FAO	USEPA 2012
Fe	49,020 ± 275	50,000	–	170 ± 1.98	150	–	0.24 ± 0.003	0.3	5
Ni	211 ± 1.02	50	–	2.25 ± 0.074	0.02	–	0.025 ± 0.005	0.02	0.2
Cu	116 ± 0.49	100	160	3.20 ± 0.021	2	1.3	0.069 ± 0.001	0.01	1
Co	300 ± 35.5	–	–	1.55 ± 0.015	0.17	–	0.03 ± 0.001	–	0.05
Zn	121 ± 0.14	300	300	4.98 ± 0.085	1.5	–	0.098 ± 0.018	–	–
Cd	11.85 ± 0.44	3	3	0.29 ± 0.006	0.2	0.005	0.034 ± 0.001	0.003	0.005
Pb	58.14 ± 0.7	100	–	1.41 ± 0.068	0.5	0.005	0.097 ± 0.002	0.05	0.015
Cr	169 ± 0.68	100	150	1.65 ± 0.015	1.2	0.5–1	0.066 ± 0.003	0.1	0.1

Results and discussion

Method validation and calibration of the instrument

The method used for this work was evaluated using a recovery test, precision (percent relative standard deviation), and calculation of the MDL and LOQ. Hence, the percentage recovery for the soil, irrigation water, and tomato samples ranged from 80 to 105%, 80–105%, and 82–95%, respectively (Supplementary Table 3). The results were in the acceptable range of 80–120%. The percent relative standard was also within the acceptable range ($<5\%$). Therefore, the method utilized in the present work is good and reliable (Voica et al., 2012). The corresponding MDLs and LOQs for the investigated metals in soil, tomato, and irrigation water ranged from 0.03 to 0.21 and 0.1–1.0; from 0.003 to 0.009 and 0.02–0.03; and from 0.003 to 0.021 and 0.01–0.07, respectively (Supplementary Table 2).

Furthermore, the calibration curve demonstrated strong linearity, with R^2 values varying between 0.9957 and 0.9999, which were greater than the permitted level for linearity (0.995) (Ancker et al., 2006; Neeta et al., 2016). The concentration of the working standards, correlation coefficient, and calibration equation of the calibration curve for each metal are shown in Supplementary Table 1.

Levels of PTMs in soil, tomato and irrigation water samples

Loading and accumulating heavy metals in the soil depends on different factors, such as the chemical form of the elements, pH, organic matter content, texture and cat ion exchange capacity (CEC) of the soil. For instance, with increasing pH, organic matter content, CEC and clay content, the percentage and availability of metals decrease. In addition, the presence of carbonate, sulfate, phosphate, and sulfide in the soil increases metal precipitation and consequently decreases metal availability to plants (Mirecki et al., 2015).

PTMs in soil samples

As shown in Table 3, the concentrations of heavy metals in the soil samples ranged from 49,020 to 11.84 mg kg^{-1}, in decreasing order of Fe > Co > Ni > Cr > Zn > Cu > Pb > Cd. The present analysis of heavy metals revealed that Fe had the highest concentration despite being slightly below the permittivity limit for iron for irrigation land (50,000 mg kg^{-1}). The high level of Fe might be due to it being the fourth most abundant element in the earth's crust after oxygen, silicon, and aluminum. The amount of Fe in this study was lower than the previously reported level in Koka Ejersa, Ethiopia (52,760 mg kg^{-1}), while it was higher than that in Mojo, Ethiopia (Gebeyehu & Bayissa, 2020; Sandeep et al., 2019). The Pb, Zn, Cu, Co, and Cd concentrations in the soil in this study were greater than those in Mojo, Koka Ejersa, and Koka Negewe, Ethiopia (Gebeyehu & Bayissa, 2020; Sandeep et al., 2019). At the same time, the Pb concentration was lower than that in the Philippi horticop, South Africa (Asaolu et al., 2012). Similarly, the concentrations of Cr in this study were greater than those in studies in the towns of Ziway and Ginch in Ethiopia. In addition, the mean concentration of Ni was also compared to that in other studies conducted in other countries and Ethiopia. The levels of Ni were greater than 35.58, 30.50, 35, and 40.33 mg kg^{-1} in the Mojo area, Koka Negewe, and Ejersa in Ethiopia, and the reported values ranged from 0 to 9.91 and 0.8.5 mg kg^{-1}, respectively, in the summer and winter seasons in Phillipi, South Africa (Gebeyehu & Bayissa, 2020; Sandeep et al., 2019). The distribution of heavy metals in soil was continuously altered, which might be due to various soil processes, different agrochemical applications, and other human activities at each sampling site under the influence of environmental factors (Brevik et al., 2015).

Generally, the results from this study showed that the concentrations of Ni, Cu, Cd, and Cr in the samples were usually higher than the WHO/FAO maximum permissible limits. The concentrations of the remaining elements, Fe, Zn, and Pb, were below this recommended value. Even though some of the HM concentrations fall below the critical permissible range, they can affect the ecosystem due to their persistent nature in the soil and their bioaccumulative nature in living organisms, which may lead to increased uptake of PTMs by plants (Atta et al., 2022).

PTMs in tomato samples

The investigated PTMs in tomatoes ranged from 170 to 0.29 mg kg^{-1} in the following decreasing order: Fe > Zn > Cu > Ni > Cr > Co > Pb > Cd (Table 3). Compared with other metals, the highest concentration of iron might be due to its usage by plants as an essential element with many important biological roles in processes such as photosynthesis, chloroplast development, and chlorophyll biosynthesis (Zhang et al., 2020a, 2020b). The level of heavy metals in tomato vegetables varies due to the bioavailability of the elements, which depends on the nature of their association with the constituents of the soil, pH, conductivity, and salinity of the irrigation water and soil. Moreover, rainfall, atmospheric dust, plant protection agents and fertilizers can also be sources of PTMs in fruit (Baruah et al., 2019).

The levels of Pb, Cu, Cd, and Cr in the tomato samples were greater than those reported in other studies conducted in Ziway, Ethiopia (near the flower garden) (Najafi & Vatanfada, 2011). At the same time, they were lower than the values found in Mojo, Ethiopia (Gebeyehu & Bayissa, 2020; Sandeep et al., 2019). Furthermore, except for Zn, the concentrations of all the selected heavy metals obtained in this study were much greater than those found in Koka Ejersa, and Koka Negewe, Ethiopia (Bayissa & Gebeyehu, 2021). The concentrations of all PTMs in the tomato (*Solanum lycopersicum*) samples from the Abuarie irrigation site were found to be above the permissible limits set by the WHO and USEPA. This may be due to the enormous use of different agrochemicals and other human activities at each sampling site.

PTMs in irrigation water samples

As shown in Table 3, the concentrations of the heavy metals in the irrigation water decreased in the order of Fe > Zn > Pb > Cu > Cr > Cd > Co > Ni, with values ranging from 0.24 (Fe) to 0.025 (Ni) mg L^{-1}. Almost all these concentration data (for Ni, Cu, Cd, Pb, and Cr) were in line with the heavy metal concentrations in irrigation water collected from the Philippi horticultural area in South Africa (Bufflap & Allen, 1995). The levels of iron, chromium, and cobalt obtained in the Abuarie irrigation water sample were found to be below the recommended maximum concentration (RMC) of the WHO/USEPA, whereas the levels of nickel, copper, cadmium, and lead were found to be above the RMC of the WHO/EPA. Therefore, the high concentrations of Cd, Pb, Ni, and Cu in the irrigation water may increase soil acidity and diminish essential phosphorous and molybdenum in the soil (G Sandeep et al., 2019). The highest levels of Cd, Pb, Ni, and Cu indicate that they originated from pesticides and herbicides that contain more of these metals (Atta et al., 2022).

Heavy metal transfer factor (TF) from soil to tomato

The TFs of Fe, Ni, Cu, Zn, Co, Cd, Pb, and Cr were 0.004, 0.01, 0.027, 0.041, 0.005, 0.025, 0.024 and 0.009, respectively, with the trend of Zn > Cu > Cd > Pb > Ni > Cr > Co > Fe. A greater transfer factor of Zn reflects relatively poor retention in soils or greater efficiency of tomato plant absorption. In contrast, the low transfer factor of Fe reflects the strong sorption of metals to soil colloids (Ugbede et al., 2021). The transferability of all the investigated PTMs was less than one, which revealed that the metal bioavailability or mobility of these heavy metals within the soil

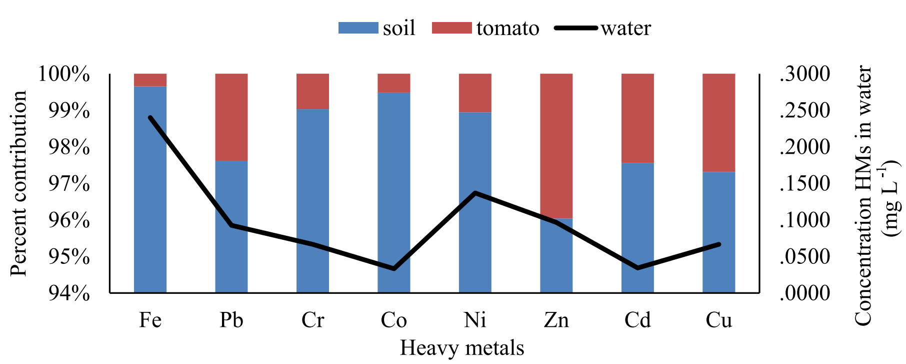

Fig. 2 The mean concentration of PTMs in irrigation water and the percentage of PTMs in soil and tomato samples

might be very low. However, the levels of PTMs in tomatoes were greater than those in the WHO, possibly due to the bioactive accumulation of PTMs in the plants. In addition, plants might absorb PTMs through leaves and steam while spraying pesticides, herbicides, and polluted rainwater (Lam et al., 2023; Mirecki et al., 2015).

Correlation analysis of PTMs

The concentrations of PTMs in the soil, tomato, and irrigation water were investigated, and the general trend was soil > tomato > irrigation water (Fig. 2). As Fig. 2 indicates, the levels of Fe, Cr, Co, and Ni in the soil were relatively high despite the low amounts in the tomatoes. This might be due to their nature (not bioavailable) in the soil or plants' low selectivity toward these metals (Mirecki et al., 2015). ANOVA was employed to determine whether the means of the concentrations of selected heavy metals (Fe, Pb, Ni, Zn, Co, Cu, Cd, and Cr) among the tomato, water, and soil samples varied significantly. Thus, almost all of the heavy metal concentrations in the soil, tomato, and water samples were significantly different at the 95% probability level ($p < 0.05$), except for Pb, Fe, and Co between tomato and water samples.

Furthermore, the relationship between each PTM within each sample type was determined using Pearson correlation, which ranges from -1 to + 1. The types of correlations that exist between each metal can be classified as follows: no correlation ($r < 0.2$), low correlation ($0.2 \leq r \leq 0.49$), low correlation, moderate correlation ($0.5 \leq r \leq 0.69$) and high correlation ($r \geq 0.7$) (Zhang et al., 2020a, 2020b). The results of the present study for the Pearson correlation coefficients between heavy metal concentrations

Table 4 Pearson correlation coefficients between heavy metal concentrations

PTMS	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
Soil sample								
Cd	1							
Co	−0.461	1						
Cr	−0.952	0.711	1					
Cu	0.161	−0.950	−0.456	1				
Fe	−0.701	−0.310	0.449	0.591	1			
Ni	−0.212	0.965	0.501	−0.999*	−0.549	1		
Pb	0.914	−0.781	−0.994	0.548	−0.351	−0.591	1	
Zn	−0.229	−0.759	−0.081	0.924	0.855	−0.903	0.186	1
Tomato sample								
Cd	1							
Co	0.189	1						
Cr	−0.945	0.143	1					
Cu	−0.277	0.891	0.577	1				
Fe	0.945	−0.143	−1.00**	−0.577	1			
Ni	0.313	0.992	0.015	0.826	−0.015	1		
Pb	−0.297	−0.994	−0.032	−0.835	0.032	−1.000*	1	
Zn	0.912	0.575	−0.728	0.141	0.728	0.675	−0.662	1
Irrigation water sample								
Cd	1							
Co	−1.000**	1						
Cr	−0.500	0.500	1					
Cu	−0.500	0.500	−0.500	1				
Fe	0.982	−0.982	−0.655	−0.327	1			
Ni	0.503	−0.503	1.000**	0.497	0.657	1		
Pb	0.500	−0.500	1.000**	0.500	0.655	1.000**	1	
Zn	0.277	−0.277	0.693	−0.971	0.091	−0.691	−0.693	1

**The correlation is significant at the 0.01 level (2-tailed).*Correlations are significant at the 0.05 level (2-tailed) in soil, tomato and irrigation water samples are summarized in Table 4. Hence, there were strong positive correlations between Co and Cr, Ni and Pb, and Cd ($r = 0.914$), as well as Zn and Cu, and Fe in the soil samples. Moderate positive correlations were also observed between Fe and Cu and between Ni and Cr. On the other hand, some of the selected heavy metals, such as Cu with Cd, Fe with Co, Ni with Cd, Zn with Cd, Zn with Cr and Zn with Pb, showed very low correlations ($r < 0.2$).

In the tomato samples, Cu with Co, Fe with Cd, Ni with Co and Cu, and Zn with Cd and Fe had strong and positive correlations. Similarly, there were also moderate positive correlations between Cu and Cr and between Zn and Co and Ni. Despite the high and moderate correlations, some pairs of PTMs, including Co–Cd, Cr–Co, Cu–Cd, Fe–Co, Ni with Cr and Fe, Pb–Cr and Fe and Zn–Cu, showed almost no correlation.

Strong positive correlations between Fe and Cd and, Pb and Ni were detected in the irrigation water samples, whereas Co with Cr, and Cu, Ni with Cd, and Fe, Pb with Cd, Cu with Fe, and Zn with Cr showed moderate positive correlations. Similarly, some pair of elements like Zn with Cd and Co have the value shows that they have almost no correlation.

Generally, strong and moderate positive correlations indicate that correlated metals might have similar sources or origins (either anthropogenic or natural), while low correlations indicate that the correlated metals might have different sources/origins (Huang et al., 2020; Jiang et al., 2022).

Health risk assessment

The hazard quotient (HQ) and hazard index (HI) parameters were used for estimating noncancer health risks, while the CR and TCR were used for estimating the probability of inhabitants developing cancer risk in their lifetime span (Hope, 2006). Moreover, Cd, As, Ni, Pb, and Co metals are grouped as probable and possible carcinogen metals, while Fe and Zn are grouped as non-cancer risk metals according to an international agency for research on cancer (IARC). Human health risk assessment can be used to evaluate the overall health impacts based on hazard identification, dose–response assessment, exposure assessment, and risk characterization (Abolli et al., 2020, 2023; Aminiyan et al., 2018; Moghtaderi et al., 2019). The PTM intake from irrigation water, soil, and tomatoes through ingestion, inhalation, and skin contact pathways was utilized to determine the adverse effects. In Table 5, the sequence values of ADD for the soil were Fe > Co > Ni > Cr > Zn > Cu > Pb > Cd for dermal contact, Cr > Fe > Co > Ni > Zn > Pb > Cu > Cd for inhalation and Fe > Cu > Co > Ni > Cr > Zn > Pb for the oral route. The ADDs of the irrigation water and tomato plants followed the trend of Cr > Fe > Pb ≈ Zn > Cu > Cd > Co > Ni and Fe > Cr > Zn > Co > Pb > Cu > Ni > Cd, respectively. The results showed that Cd had the lowest ADD, while Fe had the highest ADD among all the exposure routes for all the types of samples. Generally, the ADD decreased in the order of tomato > soil > irrigation water.

The cancer and noncancer risks for this study were evaluated by considering different exposure scenarios: (1) each metal intake by each exposure route, (2) each metal intake from each sample type, (3) each metal intake from soil by all three exposure routes, (4) all metal intake by each exposure route from each sample, and (5) all metal intake by any of the three exposure routes from any of the three sample types. Thus, the HQ_{oral}, HQ_{inh}, and HQ_{derm} parameters were used for the soil samples and were applied to

Table 5 Average daily dose (ADD) of PTMs in soil, tomato, and irrigation water samples

Sample	Exposure	Fe	Pb	Cr	Zn	Co	Ni	Cd	Cu
Soil	ADD_{oral}	4.3×10^{-4}	4.9×10^{-7}	1.5×10	6.7×10^{-7}	2.0×10^{-6}	1.8×10^{-6}	8.8×10^{-8}	7.6×10^{-6}
	ADD_{inh}	3.7×10^{-3}	4.2×10^{-4}	1.3×10^{-2}	5.8×10^{-4}	2.2×10^{-3}	1.6×10^{-3}	7.7×10^{-5}	1.9×10^{-4}
	ADD_{derm}	1.8×10^{-5}	2.1×10^{-8}	6.3×10^{-8}	2.9×10^{-8}	1.1×10^{-7}	7.9×10^{-8}	3.8×10^{-9}	2.3×10^{-8}
Water	ADD_{wat}	6.1×10^{-3}	2.5×10^{-3}	1.7×10^{-2}	2.5×10^{-3}	8×10^{-4}	6×10^{-4}	9×10^{-4}	1.7×10^{-3}
Tomato	ADD_{tom}	5.9×10^{-2}	4.93×10^{-4}	5.76×10^{-4}	1.74×10^{-3}	5.4×10^{-4}	7.86×10^{-4}	1.01×10^{-4}	1.11×10^{-3}
Overall	ADD_{tot}	6.9×10^{-2}	3.4×10^{-3}	3×10^{-3}	4.8×10^{-3}	3.5×10^{-3}	2.9×10^{-3}	1.07×10^{-3}	3×10^{-3}

ADD_{tot} is the sum of all ADD values from soil, water, and tomato.

Table 6 HQ and HI values for PTM elements in soil, tomato, and irrigation water

HM	Soil				Water	Tomato	HI_{tw}	HI_{sw}	HI_{st}	HI_{stw}
	HQ_{oral}	HQ_{inh}	HQ_{derm}	HI_s	HQ_{wat}	HQ_{tom}				
Fe	0.0034	0.0037	0.018	0.0251	0.07	0.0843	0.1543	0.0951	0.1094	0.1794
Pb	0.00013	0.00012	5.8E–06	2.56E–04	0.016	0.14	0.156	0.0163	0.1403	0.1563
Cr	0.0005	0.043	0.0021	0.0456	0.75	0.192	0.942	0.7956	0.2376	0.9876
Zn	3.3E–05	0.029	1.4E–06	0.029	0.015	0.0058	0.0208	0.044	0.0348	0.0498
Co	0.0001	0.011	5.5E–06	0.011	0.04	0.18	0.22	0.051	0.191	0.231
Ni	0.00006	0.0053	2.6E–07	0.00536	0.033	0.0393	0.0723	0.03836	0.0447	0.0777
Cd	1.7E–07	0.00015	7.6E–07	0.00015	0.0013	0.101	0.1023	0.00145	0.10115	0.10245
Cu	5.3E–07	0.024	8.7E–06	0.024	0.012	0.0277	0.0397	0.036	0.0517	0.0637
HI_{tot}	0.0042[a]	0.11627[b]	0.0201[c]	0.1405[d]	0.9373[e]	0.770[f]	1.7074[g]	1.078[h]	0.9106[I]	1.8479[j]

HI_{tot} is the total health index, [a] is HI_{oral}, [b] is HI_{inh}, [c] is HI_{derm}, [d] is $_{HI}$, [e] is HI_{wat}, [f] is HI_{tom}, [g] is HI_{tw}, [h] is HI_{sw}, [I] is HIst, and [j] is HI_{stw}

estimate the single metal noncancer risk. The HQ_{tom} and HQ_{wat} parameters were used for estimating the noncancer risk of single metals from tomato and irrigation water, respectively. The multiple-metal noncancer risk was estimated using HI_s (considering soil only), HI_{tom} (considering tomato only), HI_{wat} (considering irrigation water only), HI_{sw} (considering water and soil), HI_{st} (considering water and soil), HI_{tw} (considering water and soil), and HI_{wst} (considering irrigation water, soil, and tomato). Moreover, the cumulative risk of PTMs was also estimated using the HI_{tot} parameter (sum of HQ of each PTM in each route). The details of the results are presented in Table 6.

Noncarcinogenic health risk

The single-metal nonhazard risk of all PTMs was relatively low (HQ < 1). Although all the metal hazard quotient values were below unity, Cr and Cd contributed the most and least to the total exposure, respectively. The HQ_{tom}, HQ_{wat}, HQ_{oral}, HQ_{inh}, and HQ_{derm} values were in the order of Cr > Co > Pb > Cd > Fe > Ni > Cu > Zn; Cr > Fe > Co > Ni > Pb > Zn > Cu > Cd; Fe > Cr > Pb > Co > Ni > Zn > Cu > Cd; and Cr > Zn > Cu > Co > Ni > Fe > Cd > Pb and Fe > Cr > Cu > Pb > Co > Zn > Cd > Ni, respectively.

The overall risk of all PTMs ranged from 0.0042 (HI_{oral}) to 0.9373 (HI_{wat}), which indicates a low noncarcinogenic effect. HI_{tot} also confirmed that irrigation water had a greater impact than tomato, followed by soil. The HI values for each HM in the three routes of exposure (oral, dermal contact, and inhalation) in the soil samples followed the decreasing order of Cr > Zn > Fe > Cu > Co > Ni > Pb > Cd and ranged from 0.00015 to 0.0456. Moreover, the noncarcinogenic effect of the ingestion route is more prominent than that of dermal contact followed by the inhalation route. Similar result were reported elsewhere (Moghtaderi et al., 2019).

Single metal effects due to the intake of different nondietary (soil dust) and dietary products (tomato and water) were assessed. Thus, HI_{wt}, HI_{sw}, HI_{st} and HI_{stw} followed the ascending order of Zn < Cu < Ni < Cd < Fe < Pb < Co < Cr within the range of 0.021 and 0.0942; Cd < Pb < Cu < Ni < Zn < Co < Fe < Cr within the range of 0.0015 and 0.7956; Zn < Ni < Cu < Cd < Fe < Pb < Co < Cr within the range of 0.035 and 0.238; and Zn < Cu < Ni < Cd < Pb < Fe < Co < Cr within the range of 0.0498 and 0.9876, respectively. Cr and Zn were the highest and lowest contributors to noncancer risk under all scenarios, respectively, except at HI_{sw}, where Cd was the lowest. The HI values for each element in each combined exposure group in this study were less than 1 (HI < 1), which means that the inhabitants are relatively at risk of metal health (Arshad et al., 2020). Similarly, the total HI values for all PTMs in each combined sample were also assessed, and the obtained results showed that using $HI_{st} < HI_{sw} < HI_{wt} < HI_{stw}$ with ranges of 0.912 and 1.847 confirmed that all the values, except for $HI_{st,}$ were greater than unity. The multiple/simultaneous exposed to soil and water or water and tomato or soil, tomato, and water could develop a non-cancer risk. The total HI values for all PTMs in each sample decreased in the order of $HI_{wat} > HI_{tom} > HI_{soil,}$ with values ranging from 0.9373 to 0.141, which indicates

Table 7 Carcinogenic risk of targeted heavy metals in soil, tomato, and irrigation water

HM	Soil sample		Water		Tomato	Total cancer risk (TCR)				
	CR_{oral}	CR_{inh}	CR_{derm}	CR_{wat}	CR_{tom}	TCR_s	TCR_{sw}	TCR_{st}	TCR_{tw}	TCR_{swt}
Pb	7.23E–08	5.92E–08	3.15E–10	0.000119	2.38E–05	1.32E–07	0.000119	2.39E–05	0.000143	0.000143
Cr	0.000109	2.76E–05	7.15E–10	0.0399	0.01386	0.000137	0.040037	0.013997	0.05376	0.053897
Cd	9.45E–07	2.34E–07	4.16E–08	0.003087	3.59E–04	1.22E–06	0.003088	0.00036	0.003446	0.003447
Ni	2.69E–06	6.72E–07	1.18E–07	0.000302	0.000378	3.48E–06	0.000306	0.000381	0.00068	0.000684
CR_{tot}	0.000113[a]	2.86E–05[b]	1.6E–07[c]	0.043408[d]	0.014621[e]	0.000142[f]	0.04355[g]	0.014763[h]	0.058029[i]	0.058171[j]

CR_{tot} is the total health index, [a] is TCR_{oral}, [b] is TCR_{inh}, [c] is TCR_{derm}, [d] is TCR_s, [e] is TCR_{wat}, [f] is TCR_{tom}, [g] is TCR_{tw}, [h] is TCR_{sw}, [I] is TCRst, and [j] is TCR_{swt}

that avoiding simultaneous exposure could minimize serious chronic noncancer health risks. In total, the overall trends of the hazard indices followed the order of $HI_s < HI_{tom} < HI_{st} < HI_{wat} < HI_{sw} < HI_{wt} < HI_{stw}$.

Carcinogenic analysis

The cancer risk due to the carcinogenic metals in this study was assessed by using similar scenarios employed in noncancer risk assessments. Thus, the CR_{oral}, CR_{inh}, and CR_{derm} parameters were used for the soil samples to estimate the single metal cancer risk. The CR_{tom} and CR_{wat} parameters are used to estimate the cancer risk from a single metal in tomato and irrigation water, respectively. The cumulative or multiple-metal cancer risk was estimated using TCR_s (considering soil only), TCR_{tom} (considering tomato only), TCR_{wat} (considering irrigation water only), TCR_{sw} (considering water and soil), TCR_{st} (considering water and soil), TCR_{tw} (considering water and soil), and TCR_{swt} (considering irrigation water, soil, and tomato). Moreover, the commutative risk of metals was also estimated using the CR_{tot} parameter (sum of the CR of each PTM in each route or combined sample). The details of the results are presented in Table 7.

The single metal cancer risk of the investigated metals in oral (CR_{oral}), inhalation (CR_{inh}), dermal contact (CR_{derm}), irrigation water (CR_{wat}), and tomato (CR_{tom}) environments ranged from 1.09E–04 (Cr) to 7.26E–08 (Pb), 2.76E–05 (Cr) to 5.92E–08 (Pb), 1.18E–07 (Ni) to 3.15 E–10 (Pb), 0.0399 (Cr) to 1.19E–04 (Pb), and 0.0139 (Cr) to 2.38E–05 (Pb), respectively. The results revealed that the concentrations of all the individual metals in the tomato and water samples were above the permissible limits. A similar result was observed for Cr in the soil sample. Moreover, a single–element cancer risk from the combined sources was assessed using the total cancer risk value at different combined sources. Hence, the TCR_s, TCR_{sw}, TCR_{st}, $TCR_{tw,}$ and TCR_{swt} values ranged from 1.37E–04 to 1.32E–07, 0.04 to 1.19E–04, 0.014 to 2.39E–05, 0.0538 to 1.43E–04, and 0.0539 to 1.43E–04, respectively. The TCR_{sw}, $TCR_{tw,}$ and TCR_{swt} followed the trend Pb < Ni < Cd < Cr, whereas the TCR_s and TCR_{st} followed the trend Pb < Cd < Ni < Cr. Overall, the TCR_s, TCR_{sw}, TCR_{st}, $TCR_{tw,}$ and TCR_{swt} values are above the USEPA guidelines, except for Pb in combined soil and water samples (Taye & Chandravanshi, 2023).

The combined effects of Pb, Cd, Ni and Cr on cancer risk magnitude were investigated using TCR_{oral}, TCR_{inh}, TCR_{derm}, TCR_{wat} and $TCR_{tom,}$ and their values were found to be in the range of 0.043 (TCR_{wat}) to 1.6E–07 (TCR_{derm}), with the order of $TCR_{derm} < TCR_{inh} < TCR_{oral} < CR_{tom} < TCR_{wat}$. The results confirmed that in addition to those for TCR_{derm} and TCR_{inh}, all the results were above the guidelines set by the USEPA. In addition, multiple-metal cancer risk for soil samples and different types of combined samples were investigated, and the results followed the trend of $TCR_s < TCR_{st} < TCR_{sw} < TCR_{tw} < TCR_{swt,}$ with a range of 1.42E–04 to 0.0582. The values of TCR_s, TCR_{st}, TCR_{sw}, $TCR_{tw,}$ and TCR_{swt} were found to be above the guidelines established by the USEPA. Consequently, the risk level poses a major hazard to the inhabitants' health. Cr is the most prominent contributor to the total cancer risk as well as to the noncancer risk.

Conclusion and recommendation

The concentrations of Cr, Ni, Zn, Cd, Cu, Co, Fe, and Pb in the soil, tomato and irrigation water samples ranged from 49,020 (Fe) to 11.85 (Cd), 170 (Fe) to 0.29 (Cd) and 0.24 (Fe) to 0.025 (Ni) mg kg^{-1}, respectively. Thus, the concentrations of heavy metals in the soil, tomato, and irrigation water samples are found in decreasing order of Fe > Co > Ni > Cr > Zn > Cu > Pb > Cd; Fe > Zn > Cu > Ni > Cr > Co > Pb > Cd, and Fe > Zn > Pb > Cu > Cr > Cd > Co > Ni, respectively. The transfer factor of investigated metals to the tomato plant were follow the trend of Zn > Cu > Cd > Pb > Ni > Cr > Co > Fe. ANOVA test showed that almost all of the heavy metal concentrations in the soil, tomato, and water samples were significantly different at the 95% probability level ($p < 0.05$), except for Pb, Fe, and Co between tomato and water samples. The concentrations of all metals in tomato and Ni, Cr, Co, Cu, and Cd in the soil sample were higher than the WHO/FAO maximum permissive limits. Thus, minimizing the amounts of fertilizers and pesticides used on farmlands might be beneficial for reducing health impacts. The ADD value for Fe was greater than that for the other metals. Moreover, the ADD decreased in the order of tomato > soil > irrigation water The oral exposure route is predominant compared to inhalation and dermal contact. Even though, the HQ values in the soil, irrigation water and tomato samples were less than one, cancer and noncancer risks for both the single-metal and multimetal analyses indicated a significant health risk (HI > 1). The overall trends of the hazard indices followed the order of $HI_s < HI_{tom} < HI_{st} < HI_{wat} < HI_{sw} < HI_{wt} < HI_{stw}$, and Cr was predominantly contributed to the total cancer and noncancer risk.

There are some limitations of the study, which includes the study does not show the temporary and spatial variation of PTMs, the daily dietary consumption patterns, and quantification of PTMs in other staple foods that might underestimate the overall health impact assessments. Therefore, the following recommendations for the local community are highly recommended: (1) further research on the investigation of other local crops, fruits and vegetables sampled during different seasons; (2) longitudinal analysis of PTMs in tomato, soil, irrigation water, and other crops, fruits and vegetables; (3) quantification and health risk assessment of toxic organic contaminants; (4) cooking of tomato with excess water and then discarding of the water might reduce the level of PTMs that consume cooked tomato; and (5) minimizing the use of large amounts of pesticides and herbicides.

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Consent for publication We agree that the manuscript submitted to your journal has not been published elsewhere and has not been simultaneously submitted to other journals.

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