



Assessment of heavy metal contamination in soils, dust and plants grown in Drâa Lasfar region in Marrakech, Morocco

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Article Info	Abstract
Article type: Research Article Article history: Received: February 2025 Accepted: October 2025 Corresponding author: Kh.flata@gmail.com Keywords: Heavy metals Drâa Lasfar mine region Contamination health risk Marrakech	The contamination of soils, dust, and plants by heavy metals poses a significant global concern due to its inherent risks. In the Drâa Lasfar region of Marrakech, Morocco, toxic heavy metals such as lead (Pb), cadmium (Cd), and copper (Cu) have been found to exceed the maximum allowable concentrations set by FAO/WHO. Soil samples from the region show significant contamination levels, with Pb (172.6 µg/g), Cu (142.1 µg/g), and Cd (9.1 µg/g) concentrations surpassing threshold limits. Furthermore, the contamination assessment, as indicated by the contamination factor (CF) and pollution index (PI) values, confirms the significant pollution of the studied soils. Dust samples collected from both indoor and outdoor environments exhibit considerably higher concentrations of Pb, Cd, and Cu compared to background levels, underscoring the outdoor dust as a significant source of metal contamination. Additionally, the concentration of Pb in plants exceeds FAO/WHO maximum permissible limits, with roots showing higher accumulation rates compared to other plant parts. The ecological and human health risks associated with heavy metal contamination are evident from the calculated ecological risk index (ERI) and health risk index (HRI) values, which indicate severe health risks posed by Pb contamination in the studied area. The findings emphasize the urgent need for mitigation measures to address the health risks posed to the local population, particularly children, by the contamination of plants grown in proximity to mining activities.

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Introduction

Environmental pollution and food safety are major concerns in modern society (Al-Mubaidin et al., 2022). The expansion of global industrialization has fueled extensive mining activities, resulting in the widespread utilization of metalliferous ores and a notable increase in mining operations (Hussien et al., 2022; Calmuc et al., 2020). However, these activities come with a significant environmental cost, as they are inherently polluting and pose risks to both environmental quality and human health (Jung, 2001; Navarro et al., 2008; Su et al., 2024). In Morocco, mining serves as a fundamental pillar of the country's economy, with vast areas designated as metalliferous sites. Nevertheless, these mining activities serve as primary sources of heavy metal contamination (Muhammad et al., 2024; Barkouch and El Fadeli, 2024; Pruvot et al., 2006). Among the various pollutants generated by mining, heavy metals are particularly concerning due to their potential to compromise food safety (Angon et al., 2024). While metals like copper, zinc, iron, and chromium are essential in low concentrations for biological functions, elevated levels can be toxic and lead to significant health complications. Highly toxic metals such as lead, mercury, and arsenic are classified as hazardous air pollutants (Lee and Chan, 2003). Exposure pathways to these hazardous elements include the ingestion of vegetables cultivated in contaminated soils or inhalation of dust adhering to plants (Kicińska and Wikar, 2024). The soil-crops-human system is recognized as the primary route for human exposure to environmental heavy metals in agricultural regions (Khan et al., 2008). Additionally, Individuals may be exposed to heavy metals through contaminated dust by ingestion, inhalation, or absorption through the skin (Safiur Rahman et al., 2019). This contamination of the urban food chain has severe public health implications (Gizaw, 2019). In the vicinity of mining sites, soils, plants, water bodies, and dust are susceptible

to contamination by potentially toxic elements transported by wind and water currents (Elhaya et al., 2023).

Mining activities have detrimental effects on the environment due to the significant accumulation of heavy metals resulting from operational or abandoned mines. Regrettably, in Marrakech, limited efforts have been made to assess the concentration of heavy metals in the soils, plants, and dust of the Draâ Lasfar mining area. The objective of the present study is to comprehensively evaluate the extent of heavy metal contamination in soils, dust, and various plants cultivated in the Drâa Lasfar region of Marrakech in order to provide information about the status of the potential health effect generated by the consumption of these plants in this region.

Materials and methods

Study area

The still functional Draâ Lasfar mine is situated approximately 13 km northwest of Marrakech (Figure 1). Closely positioned to the Tensift River, the Drâa Lasfar mine is an operational underground facility primarily focused on the extraction of zinc and lead. The surrounding region is predominantly agricultural (Barkouch and El Fadeli, 2024)

Soil samples

A number of 60 soil samples were collected from various stations during four sampling campaigns conducted between 2020 and 2022, covering seasonal variations and allowing for a more comprehensive analysis of soil composition.

Soil samples were collected randomly from the upper layer (0-20 cm) and then mixed to obtain representative samples before being transported to the laboratory. Air-dried, representative soil samples were sieved through a 2 mm mesh and stored in plastic envelopes until analysis of the main physicochemical properties and total metallic pollutant contents (Barkouch and El Fadeli, 2024)

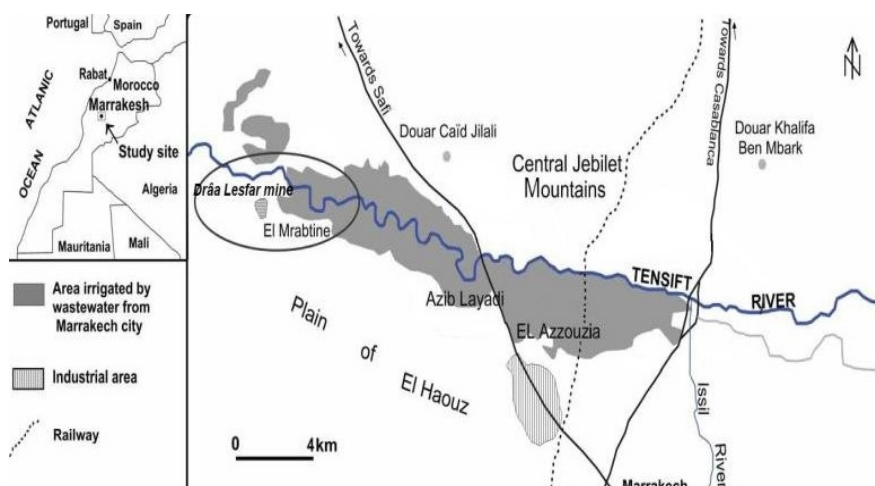


Figure 1. Draâ Lasfar mine geographic situation in Marrakech Region.

Digestion of soil samples

Precisely 0.5 g of each representative sample was gradually heated to 450 °C. After cooling, the acid digestion of the samples consisted of adding 3 ml HNO₃, 6 ml HCl and 3 ml HF. The mixture was heated to dryness, then diluted with deionized water before analyzing by atomic absorption spectroscopy (Brakouch et al., 2015).

Samples analysis

Soil pH, electrical conductivity (EC) and organic matter (OM) content were determined following the standard analytical methods (Barkouch et al., 2015). The metal analyses (Pb, Cd and Cu) of samples were carried out by using UNICAM atomic absorption spectrophotometer (AAS).

Data analysis

The Contamination Factor (CF) serves as a quantitative measure used to illustrate the concentration trend of metals in soils. It quantifies the degree of contamination in relation to either the average crustal composition of the specific metal or the measured background values obtained from geologically similar and uncontaminated area (Kumar et al., 2019; Jimoh et al., 2020). It is expressed as:

$$CF = C_m / C_r \quad (1)$$

C_m represents the average concentration of metal m in the soil, while C_r denotes the reference concentration (value) of metal "m," which is obtained either from literature sources (such as the average crustal

abundance) or directly determined from a material with similar geological characteristics (Jimoh et al., 2020).

Plant sampling and identification

Only the most common plant species were selected for sampling. All plants were fully matured, appeared healthy, and showed no signs of parasitic infestation. To eliminate airborne pollutants, the plants were first washed with tap water and then rinsed with distilled water (Kyungdeok et al., 2019). To minimize water content, the vegetable samples were weighed and air-dried for 24 hours. Once dried, the samples were ground into a fine powder using a pestle and mortar, sieved, and then stored in sealed paper envelopes until further analysis (Kyungdeok et al., 2019).

Digestion of plant samples

A number of 30 samples per plant species were collected during four sampling campaigns conducted between 2020 and 2022, covering seasonal variations and ensuring reliable statistical representativity. The plant samples were washed with deionized water and dried in a forced-air oven at 60°C for 48 hours. The dried plant parts were then ground using a stainless-steel blender and passed through a 2-mm sieve. For each sample, 1 g of plant material was ashed in a muffle furnace at 550°C for 4 hours (Avila et al., 2012). After cooling to room temperature, 1 ml of HNO₃ was added, the mixture evaporated on a sand bath, and

the sample was re-ashed in the muffle furnace at 550°C. This procedure was repeated until the ash turned white. The ash was then dissolved in 5 ml of 5% HCl and transferred to a 10 ml flask for analysis (Elhaya et al., 2023)

Data analysis

Calculation of transfer factors (TF)

The transfer factor (TF) serves as an index reflecting the vegetable's capacity to accumulate specific metals relative to their concentrations in the soil substrate (Cui et al., 2004). For each metal, it was calculated using the following expression:

$$TF = \frac{\text{Metal concentration in plant tissue}}{\text{Metal concentration in soil}}$$

Calculation of oral intake of metals from vegetables

The daily intake of metals (DIM) was determined using the equation:

$$DIM = \frac{C_{\text{metal}} * C_{\text{factor}} * D_{\text{food intake}}}{BW_{\text{average}}}$$

where C_{metal} is the metal concentration in plants (mg/kg), C_{factor} is the conversion factor for fresh vegetable weight to dry weight, $D_{\text{food intake}}$ is the daily intake of vegetables and BW_{average} is the average body weight. The conversion factor (0.085) was applied to convert fresh green vegetable weight to dry weight, as per Rattan (El Fadeli et al., 2014). The average daily vegetable consumption for adults and children was considered to be 0.345 kg/person/day and 0.232 kg/person/day, respectively, while the average adult and child body weights were

assumed to be 55.9 kg and 32.7 kg, respectively (Ismaili et al., 2024).

Calculation of health risk index of metal contamination of vegetable

The health risk index for the local population, through the consumption of contaminated vegetables, was defined as the ratio of estimated daily metal intake (DIM) from soil via the food chain to the reference dose (RfDo) for Pb (El Hamiani et al., 2015). The risk index was therefore calculated as follows:

$$\text{Risk Index} = \text{DIM} / \text{RfDo}$$

RfDo represents safe levels of exposure by oral for lifetime (Salazar-Camacho et al., 2022). The HRI under 1 means the exposed population is assumed to be safe.

Dust samples

Dust samples were collected from 50 sites (25 indoors and 25 outdoors) to ensure sufficient representativity. Sampling was conducted on the ground, at various locations inside (doors, windows) and outside the dwellings, using the wipe sampling method with an alcohol-impregnated filter paper (Middleton et al., 2018).

Results and discussion

Soil properties

Heavy metal trace elements (MTE) pose a significant environmental hazard, especially in areas near mining activities. The uptake of MTE by crops is primarily influenced by the physico-chemical properties of the soil and the species of plant (Ma et al., 2022). Table 2 displays the key soil properties of the tested soils.

Table 2. Physicochemical characteristics of soils.

	Draâ Lasfar Soil (DLS)			Control Soil (CS)			Contamination factor
	N	Mean	ET	N	Mean	ET	
pH	8	6.97	0.66	2	7.87	0.16	
EC	8	0.196	0.07	2	0.21	0.03	
TL	8	0.71	0.47	2	0.49	0.03	
OM	8	1.23	0.81	2	0.84	0.01	
Pb	8	172.55	81.51	2	15.97	0.04	10.80
Cd	8	9.06	0.14	2	0.89	0.25	10.18
Cu	8	142.11	23.16	2	12.16	0.098	11.69

The soil pH measurements revealed that the soil sample was slightly acidic, with a pH of 6.97. This pH value was lower compared to previous studies conducted in the same area (El Gharmali, 2005; Barkouch et al., 2007; El Adnani et al., 2008), but closer to the findings reported by Boularbah et al., (2006) for agricultural soils sampled in five mines in southern Morocco, as well as those obtained by Mico et al., (2006) for agricultural soils in Spain. The observed increase in soil pH could be attributed to the reduced irrigation of soil with sewage. Typically, the application of sewage induces changes in certain physicochemical characteristics of the soil. Consequently, alterations in soil pH are dependent on the pH of the utilized wastewater and the water originating from the mine (Barkouch et al., 2023). The results indicated that the application of sewage and mine water caused a decrease in soil pH by 0.9 units compared to the control soil. The electrical conductivity (EC) of the examined sample was lower than 4mS/cm, indicating good soil salinity according to USDA criteria (Mu et al., 2024). The organic matter (OM) content values were relatively low compared to values previously reported in the same area (Barkouch et al., 2007; El Adnani et al., 2008; Ait Melloul et al., 2024) as well as in other areas with similar conditions (Esshaimi et al., 2012; Zhuang et al., 2010; Khan et al., 2010; Zhuang et al., 2009; Liu et al., 2005). The low OM content could be attributed to the intensive use of these soils and the rapid mineralization of organic matter under semi-arid conditions (Mu et al., 2024; Mico et al., 2006). Additionally, it may be related to the poor adsorption of organics on negatively charged quartz grains, which are predominant in the solid tailings of the Draâ Lasfar mine (Barkouch et al., 2015).

Heavy metals content

Descriptive statistics for heavy metals content of soil and pollution factor from the study area are shown in Table 2. The ranking order of the heavy metals' mean values in soils of Draâ Lasfar mining area was: Pb > Cu > Cd; indicating that Pb followed by Cu was in the maximum concentrations while

Cd was in minimum concentration. The Copper (Cu) is considered essential for living organisms; its mean value was 142.11 µg/g. Cadmium (Cd) and Lead are not essential elements for plants and moreover, they are toxic; especially Cd which is generally related to human activities (Haider et al., 2021). In spite of its low quantity in the soil, Cd is toxic at much lower concentrations than the other elements analyzed in this study. Its mean values were 9.06 µg/g and 172.55 µg/g respectively.

The concentrations of toxic heavy metals, namely Cd and Pb, as well as the micronutrient Cu, in the soil of Draâ Lasfar exceeded those found in the reference soil. The highest measured concentrations of Pb, Cd, and Cu in agricultural soils all surpassed the permissible values set by the WHO in 1993, with Pb reaching 172.55 µg/g. These findings suggest that the soils in the study area are contaminated and fail to meet the quality criteria for agricultural soils. Nonetheless, the concentrations of the analyzed toxic metals are notably lower than those reported in previous years for the same region (Barkouch, 2024; Ait Melloul et al., 2023; El Adnani, 2008) and in mining areas in other countries (Ma et al., 2014; Li et al., 2007; Mico et al., 2006).

The FP values for Cu, Cd, and Pb were calculated as 1.31, 1.69, and 3.83, respectively. Notably, all recorded values exceeded 1, confirming the contamination of the studied soil. The average concentrations of Cd, Cu, and Pb significantly differ from those of the reference soil ($p < 0.0001$). Despite efforts to reduce wastewater irrigation and control the spread of mine waste, these results clearly indicate that long-term contamination from sewage and waste has led to a substantial accumulation of Cd, Cu, and Pb in agricultural soils. Furthermore, the elevated concentrations of MTE, particularly Pb and Cd, pose a potential risk to public health, especially for young children. This poses a significant challenge for agricultural soils receiving waste inputs such as sewage sludge (Elhaya et al., 2023), which can impact soil flora and consequently lead to crop contamination.

Lead concentration in different plant parts

Bioaccumulation of Pb was analyzed in roots, barks, stems and aerial parts of the following species (*Citrus Limon*, *Prunus armeniaca*, *Triticum turgidum*, *Hordeum vulgare*, *Vicia faba*, *Brassica rapa* L., *Allium cepa*, *Mentha* spp, *Rosmarinus officinalis* L.,

Artemisia absinthium L., *Petroselinum crispum*). The selected samples represented the most frequently plants species encountered in this study area. Pb concentrations obtained in different parts of the plants are represented in Table 3.

Table 3. Mean concentrations of Pb in different parts of twelve species cultivated in the mining area.

<i>Citrus Limon</i>	DLS CS	Roots	Barks	Stems	Leaves	Fruits
		ND	4.49 ± 2.56 0.40 ± 0.04	ND	5.64 ± 2.50 0.39 ± 0.03	ND
<i>Prunus armeniaca</i>	DLS CS	ND	6.79 ± 0.62 1.41 ± 0.04	ND	7.31 ± 0.83 1.37 ± 0.03	3.05 ± 2.23 0.14 ± 0.07
<i>Triticum turgidum</i>	DLS CS	23.66 ± 12.69 4.69 ± 0.17	4.05 ± 1.62 0.50 ± 0.24	2.84 ± 1.18 0.53 ± 0.08	10.50 ± 6.81 0.41 ± 0.06	ND
<i>Hordeum vulgare</i>	DLS CS	2.39 ± 0.78 0.13 ± 0.03	ND	0.75 ± 0.49 0.01 ± 0	1.06 ± 0.03 0.14 ± 0.07	3.85 ± 1.29 0.23 ± 0.06
<i>Vicia faba</i>	DLS CS	3.19 ± 0.93 2.70 ± 0.04	ND	2.44 ± 0.32 1.40 ± 0.04	2.29 ± 1.24 1.37 ± 0.11	2.17 ± 1.24 2.17 ± 0.11
<i>Brassica rapa</i> L.	DLS CS	2.01 ± 1.76 2.01 ± 0.04	ND	1.24 ± 0.14 0.04 ± 0	6.96 ± 1.28 0.70 ± 0.04	2.80 ± 2.52 0.35 ± 0.03
<i>Allium cepa</i> .	DLS CS	4.80 ± 1.37 0.97 ± 0.07	ND	3.17 ± 1.98 0.71 ± 0.08	4.22 ± 2.81 0.31 ± 0.13	3.47 ± 2.87 0.23 ± 0.03
<i>Mentha</i> spp	DLS CS	10.03 ± 0.49 0.70 ± 0.04	ND	5.58 ± 1.39 1.45 ± 0.42	9.09 ± 0.53 1.31 ± 0.03	ND
<i>Rosmarinus officinalis</i>	DLS CS	10.17 ± 0.96 0.27 ± 0.03	ND	ND	8.14 ± 0.44 0.13 ± 0	ND
<i>Artemisia absinthium</i>	DLS CS	12.19 ± 1.21 0.78 ± 0.10	ND	ND	10.25 ± 2.44 1.03 ± 0.06	ND
<i>Petroselinum crispum</i>	DLS CS	11.24 ± 0.77 1.34 ± 0.03	ND	5.12 ± 1.12 1.13 ± 0.08	8.37 ± 0.66 0.90 ± 0.04	ND

N.D: not determined

The results presented in Table 3 reveal significant variations in lead concentrations across different parts of the studied plants and among different plant species, with a notable accumulation in the roots compared to other plant parts. Lead concentrations range from 2.01 ± 1.76 µg/g for *Brassica rapa* L to 23.66 ± 12.69 µg/g for *Triticum turgidum*. Leaves exhibit the second highest concentration of lead among the studied parts, ranging from 1.06 ± 0.03 for *Hordeum vulgare* to 10.50 ± 6.81 for *Triticum turgidum*. Overall, the lead concentrations in all parts of Draâ Lasfar plants studied were significantly high. Notably, the roots and leaves of *Triticum turgidum* recorded the highest concentrations of lead, at 23.66 and 10.50 µg/g, respectively, indicating a tendency for this species to hyper-accumulate certain heavy metals when

present in the atmosphere, soil, and water resources. Additionally, significant contamination is observed in barks and stems. This excessive accumulation of Pb by *Triticum turgidum* is due to its dense and fibrous root system, which increases the surface area for metal uptake from the soil (Zhou et al., 2020). The presence of lead in the food chain poses a health hazard to human consumers, as Pb^{2+} is associated with hematological, neurological, renal, gastrointestinal, physiological, and carcinogenic effects.

Furthermore, elevated concentrations of lead (Pb) have been observed in the roots and leaves of various plant species, including *Mentha* spp, *Rosmarinus officinalis* L, *Artemisia absinthium* L, and *Petroselinum crispum*, with values ranging from 10.03 to 12.19 µg/g in roots and 8.14 to 11.24 µg/g in

leaves. This phenomenon suggests that these particular species, such as *Citrus Limon*, *Prunus armeniaca*, *Hordeum vulgare*, *Vicia faba*, *Brassica rapa* L, and *Allium cepa*, may exhibit a degree of adaptation to Pb contamination owing to their inherent tolerance. Notably, the concentrations of trace elements in the aerial parts of aromatic and medicinal plants, such as *Mentha spp*, *Rosmarinus officinalis* L, *Artemisia absinthium* L, and *Petroselinum crispum*, are notably high. These plants typically demonstrate rapid growth and possess high rates of transpiration, facilitating the uptake of metals by their roots and subsequent translocation to aerial tissues.

However, it is noteworthy that most of these plants exhibit lower contamination levels in their stems compared to their roots and

leaves (e.g., 5.58 µg/g of Pb in *Mentha spp* stems and 5.12 µg/g of Pb in *Petroselinum crispum* stems). This discrepancy suggests that the contamination of aerial parts may be attributed to dust deposition, particularly considering their proximity to the ground and susceptibility to physical contamination from soil dust and splash. Such factors may contribute to the higher concentrations of heavy metals observed in these leafy vegetables.

DIM and HRI of heavy metals

The data presented in Table 4 depict the values of DIM (Daily Intake of Metals) calculated for adults and children. These findings unveil that the daily intake of metals was notably elevated for vegetables cultivated in the Draâ Lasfar mine area.

Table 4. The results of the daily intake of ETM and the index of the health risk associated with the consumption of the studied plants for the residents of Azzozia Mining area.

Plants	Individuals	Indices	DLS
<i>Triticum turgidum</i>	Children	AJM	6.19 E-3
		IRS	1.77
	Adults	AJM	5.38 E-3
		IRS	1.54
<i>Mentha spp</i>	Children	DIM	4.97 E-3
		HRI	1.42
	Adults	AJM	4.32 E-3
		IRS	1.23
<i>Rosmarinus officinalis</i> L.	Children	AJM	5.52 E-3
		IRS	1.58
	Adults	AJM	4.80 E-3
		IRS	1.37
<i>Artemisia absinthium</i> L.	Children	AJM	6.77 E-3
		IRS	1.93
	Adults	AJM	5.89 E-3
		IRS	1.68
<i>Petroselinum crispum</i>	Children	AJM	5.91 E-3
		IRS	1.69
	Adults	AJM	5.14 E-3
		IRS	1.47

Rfd for Pb (0.0035 mg/Kg/day).

For the examined plants, DIM was observed to be highest for *Artemisia absinthium* L and *Petroselinum crispum*, with values of 6.77 E-3 and 5.91 E-3 respectively for children, and 5.89 E-3 and 5.14 E-3 for adults. The daily intake of lead ranged from 4.32 E-3 to 5.89 E-3 for adults, and from 4.97 E-3 to 6.77 E-3 for children. Notably, DIM values appear to

be particularly elevated for children.

The Health Risk Index (HRI) for heavy metals associated with the consumption of vegetables grown in the mining area was calculated for both adults and children, with the results presented in Table 4. The HRI serves as a valuable parameter for assessing the risks associated with consuming food

contaminated by ETM. The highest HRI is observed for children consuming *Artemisia absinthium* L and *Triticum turgidum*, with values of 1.93 and 1.77 respectively. For lead, the HRI ranges from 1.23 to 1.68 for adults and from 1.42 to 1.93 for children. Furthermore, it is noteworthy that the HRI values obtained for all studied plants exceed 1. DIM values for both adults and children surpass the safe limits (Elhaya et al., 2023). The elevated DIM through the consumption of contaminated vegetables may pose significant health risks due to lead ingestion from plants grown in the mining area. The DIM and HRI values for the studied area indicate that all analyzed plants present severe health risks related to lead contamination. Consequently, greater attention should be directed towards understanding the potential health risks of ETM for the local populations, particularly children, residing in this area.

Several practical measures can be recommended to reduce heavy metal exposure in the local population:

- Phytoremediation by using certain plant species that can absorb and accumulate

heavy metals to gradually reduce heavy metals soil contamination (Hui et al., 2023).

- Soil Amendments by applying materials like biochar, lime, or organic matter to immobilize metals, reducing their bioavailability for crop uptake (Jackson et al., 2022).
- Water Quality Improvement by ensuring that irrigation water is free from heavy metal contaminants by treating wastewater or sourcing water from cleaner supplies, thereby preventing further contamination of agricultural soils (Barkouch and El Fadeli, 2024; Elhaya et al., 2023).

Pollution and transfer factor of metals from soil to vegetables

Table 5 presents the pollution factor for lead (Pb) and the transfer factor (TF) in vegetables cultivated in the study area. The TF for vegetables grown in the area of interest varies from 0.01 to 0.09. *Triticum turgidum* exhibits the highest TF, while *Vicia faba* and *Brassica rapa* L show the lowest TF values.

Table 5. Pollution factors and transfer factors of Pb in twelve plants in the mining area.

	Pollution Factors	Transfer Factors
<i>Citrus Limon</i>	12.82	0.03
<i>Prunus armeniaca</i>	5.72	0.04
<i>Triticum turgidum</i>	6.70	0.09
<i>Hordeum vulgare</i>	15.78	0.02
<i>Vicia faba</i>	1.32	0.01
<i>Brassica rapa</i> L	4.20	0.01
<i>Allium cepa</i> .	7.05	0.03
<i>Mentha spp</i>	7.14	0.07
<i>Rosmarinus officinalis</i> L.	45.78	0.08
<i>Artemisia absinthium</i> L.	12.40	0.09
<i>Petroselinum crispum</i>	7.34	0.03

In general, the metal transfer factor serves as a tool to assess the potential of plants to uptake environmental trace metals (ETM) from the soil into their edible tissues, playing a crucial role in human exposure to heavy metals through the food chain. It constitutes a fundamental parameter for evaluating the human health risk index. Metal TF varies significantly among different vegetable

species, with notably high values observed in *Triticum turgidum* and *Artemisia absinthium* L, followed by *Rosmarinus officinalis* L. and *Mentha spp*. Despite TF values being below 1 for all vegetables, indicating low metal uptake efficiency, the high total concentrations of Pb in the soil result in an extremely low extractable fraction, potentially limiting metal absorption by plant

roots. Leafy vegetables such as *Artemisia absinthium* L, *Rosmarinus officinalis* L, and *Mentha spp.* exhibit higher metal uptake concentrations compared to other vegetables, possibly due to their high transpiration rates, which support plant growth and may facilitate increased metal absorption. Furthermore, additional sources of Pb contamination in aboveground plant parts, such as dust deposition, may be present in the area. Undoubtedly, the heavy metals mining activities and the significant vehicular traffic in the vicinity of the study area contribute to a saturated atmosphere with toxic metals, potentially leading to

metal deposition on vegetable leaves (Elhaya et al., 2023).

Levels of heavy metals in outside and inside homes dust

Table 6 provides descriptive statistics for the concentrations of metals (Pb, Cd, and Cu) in dust samples collected from both outside and inside dwellings of the mining area. The presence of high standard deviations for certain cases highlights the considerable variability observed within the analyzed samples, indicating significant heterogeneity in the dust composition.

Table 6. Mean concentrations of Pb, Cd and Cu of dust inside and outside dwellings of the mining area.

		Pb ($\mu\text{g}/\text{m}^2$)	Cd ($\mu\text{g}/\text{m}^2$)	Cu ($\mu\text{g}/\text{m}^2$)
Inside	Windows (n=4)	86.06 $\pm$ 68.54	3.49 $\pm$ 3.53	44.17 $\pm$ 29.65
	reference (n=2)	12.40 $\pm$ 0.91	0	3.48 $\pm$ 0.45
	inside (n=4)	49.28 $\pm$ 17.35	2.73 $\pm$ 2.52	27.51 $\pm$ 17.30
	reference (n=2)	10.17 $\pm$ 1.02	0.08 $\pm$ 0.02	9.97 $\pm$ 0.14
Outside	Outside (n=4)	261.30 $\pm$ 22.94	53.53 $\pm$ 8.35	376.78 $\pm$ 38.13
	reference (n=2)	15.65 $\pm$ 0.14	3.23 $\pm$ 1.31	11 $\pm$ 0.03
	Windows %	32.93	6.51	11.72
	Inside %	18.85	5.10	7.30

% in Pb of the windows= [in Pb of the windows]/[in Pb outside]*100 , % in Pb of the doors= [in Pb of the doors]/[in Pb outside]*100

The mean concentrations of Pb, Cr, and Cd in both outdoor and indoor dust samples surpass their background values significantly. Outdoor samples exhibit the highest metal concentrations, notably copper with a mean concentration of 376.78 $\pm$ 38.13, followed by lead and cadmium with concentrations of 261.30 $\pm$ 22.94 and 53.53 $\pm$ 8.35 respectively. Elevated levels of ETMs are also detected on windows, notably lead and chromium, surpassing their reference values by a significant margin. While indoor dust samples generally show lower concentrations of ETMs compared to outdoor samples, they still pose concerns as their levels exceed reference values. These findings underscore the windowsill dust as a significant contamination source. The observed metal concentration ranges are indicative of toxicity, posing potential health risks, especially for children. Besides mining activities in the area, other sources contributing to metal dust pollution include industrial activities, traffic emissions, and

nearby construction works. Lead contamination, for instance, can be attributed to the use of leaded gasoline, while copper and cadmium may originate from tire and vehicular component wear (Olowoyo et al., 2022).

Overall, the concentration variation of indoor dust is largely influenced by external sources, indicating significant contributions from outdoor contamination. However, the levels observed in our samples remain lower than those reported in previous studies (Glorennec et al., 2012; Hassan, 2012; Turner, 2007; Turner and Simmonds, 2006). The proportion of ETMs, particularly lead, on windows exceeds that found indoors (32.93% and 18.85% respectively). This discrepancy is attributed to the downwind transport of waste deposited in open areas to neighboring houses around the mine. Some dust settles in agricultural soils outside the residences, while the remainder, containing Pb, Cd, and Cu, is carried to household windows. Subsequently, these contaminants

are introduced indoors through human contact, clothing, footwear, or animals.

In general, the presence of ETMs in the dust is primarily linked to external contaminated sources, alongside indoor activities such as cooking, smoking, and the use of cleaning products (Al-Momani, 2007; Yaghi and Abdul-Wahab, 2004).

Conclusion

Long-term mining and wastewater irrigation operations have resulted in the contamination of agricultural soils, vegetables, and dust in the studied area. Based on metal concentrations, nearly all determined metals in agricultural soils, plants, and dust in the mining area exceed their background values.

Agricultural soils and plants are significantly impacted by heavy metals from wastewater irrigation, mining waste and likely atmospheric deposition. However, dust contamination primarily originates from mining activities in this region. Pb contamination levels often surpass those of other metals.

The study findings highlight significant health concerns associated with plants cultivated in contaminated soils and exposed to contaminated dust. Most food crops analyzed contain elevated concentrations of Pb, exceeding safety limits established. Similarly, both outside and inside dust samples exhibit high trace metal

concentrations exceeding reference values.

The mobilization of heavy metals into the environment due to human activities has become a notable process in the geochemical cycling of these metals. This is particularly evident in mining areas, where various activities emit substantial quantities of heavy metals into the atmosphere, plants, and soil, surpassing natural emission rates. This high level of contamination of plants in proximity to mining activities poses significant health risks to the local population, necessitating urgent attention and mitigation measures to safeguard public health, particularly among vulnerable groups like children.

Given these findings, it is imperative to implement mitigation measures to reduce heavy metal exposure. For instance, the adoption of phytoremediation strategies using metal-accumulating plants could gradually reduce soil contamination, and dust control measures (such as regular cleaning and the installation of physical barriers) can help limit the spread of contaminated particles into residential areas. Additionally, enhancing soil management practices through the use of amendments like biochar or lime may immobilize metals, reducing their uptake by crops.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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