International Journal of Agricultural Technology 2026 Vol. 22(3):1267-1278
DOI: https://doi.org/10.63369/ijat.2026.22.3.1267-1278
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Heavy metals in soil and their bioaccumulation in carrots

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Musa, F. and Musa, S. (2026). Heavy metals in soil and their bioaccumulation in carrots. International Journal of Agricultural Technology 22(3):1267-1278.

Abstract The present study investigated the concentrations of selected heavy metals in soil and carrot samples collected from six locations in Kosovo. Results demonstrated significant differences in metal content with respect to locality, substrate type, metal type, and their interactions. The accumulation of heavy metals in carrots generally reflected the mean concentrations in the corresponding soils, with the exception of chromium, which was detected in higher levels than lead in carrot tissues, following the order: Fe > Zn > Cu > Cr > Pb > Cd > As. These findings provide important insights into heavy metal bioaccumulation in vegetables and highlight potential risks for environmental pollution and food safety in Kosovo.

Keywords: Heavy metals, Soil contamination, Bioaccumulation factor, *Daucus carota*, ANOVA

Introduction

Vegetables constitute a fundamental component of the human diet, as they provide carbohydrates, proteins, vitamins, minerals, dietary fibre, and other essential compounds necessary for maintaining human health. Regular consumption of vegetables has been associated with a reduced risk of chronic diseases, which contributes to their widespread acceptance among consumers (Hu *et al*., 2013). In addition, vegetables represent one of the primary routes through which the human body acquires essential minerals required for proper physiological development. However, alongside beneficial nutrients, vegetables may also accumulate hazardous substances, particularly heavy metals, which can cause toxicity and pose significant health risks when they accumulate over extended periods. As integral elements of daily nutrition, vegetables can act as important carriers of heavy metals. These elements are considered major environmental pollutants due to their toxicity, persistence, and non-biodegradable nature (Nwuche and Ugoji, 2008). One of the most pressing global environmental concerns is the contamination of soils with heavy metals, especially in industrial regions, which subsequently affects agricultural land. Heavy metals naturally occur in the Earth's crust and are typically defined by a

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density greater than 5 g/cm^3. The presence and accumulation of heavy metals in soil, as well as in the edible parts of vegetables, represent a serious issue for both environmental quality and food safety (Gupta *et al*., 2022).

Certain heavy metals play a beneficial role as micronutrients for both humans and animals when present in trace concentrations. However, others such as cadmium (Cd), arsenic (As), and chromium (Cr) are recognized for their carcinogenic properties. Contamination of soils with these elements facilitates their uptake and accumulation in plants, which subsequently enter the human food chain, posing considerable health risks and contributing to the onset of various diseases (Mao *et al*., 2023). The accumulation of heavy metals in plants represents a major global concern due to their toxic nature, widespread occurrence, persistence, and tendency to bioaccumulate (Hu *et al*., 2017). Numerous studies have demonstrated a strong and positive relationship between the concentration of heavy metals in vegetables and their levels in the soils where they are cultivated. Consequently, soil remediation has become an important focus of recent research efforts (Ye *et al*., 2015).

Soil contamination with heavy metals is mainly attributed to anthropogenic activities, including irrigation with wastewater, disposal of solid waste, application of sewage sludge, emissions from vehicles, and various industrial processes (Odoh *et al*., 2013).

Enhanced uptake of heavy metals by crops, including vegetables and fruits grown in contaminated soils, has been widely reported across different regions of the world (Khan *et al*., 2008; Lăcătuşu and Lăcătuşu, 2008; Liu *et al*., 2005). Vegetables cultivated under such conditions tend to accumulate considerable amounts of these elements, which may pose serious health risks to consumers (Singh *et al*., 2010). Due to their slow elimination from the human body, heavy metals gradually accumulate in different organs, potentially causing DNA damage and contributing to the development of chronic and neurological disorders, including ulcerative colitis, Crohn's disease, depression, Parkinson's disease, Alzheimer's disease, Wilson's disease, cardiovascular conditions, and cancer (Ozbolat and Tuli, 2016; Roba *et al*., 2016).

Heavy metals are among the most commonly detected contaminants in environmental compartments and have attracted significant attention because of their toxicity, persistence, bioaccumulative characteristics, and potential risks to both ecosystems and human health (Burges *et al*., 2015; Wu *et al*., 2018). Their presence in soils may originate from natural sources such as parent rock material, as well as from anthropogenic inputs including agricultural practices, waste disposal, and industrial emissions (Huda *et al*., 2024).

According to Odoh *et al*. (2013), the concentrations of cadmium (Cd), manganese (Mn), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in fruits and vegetables sold along major roads and traffic intersections were higher compared to those obtained from uncontaminated control areas. Furthermore, numerous studies have investigated both the individual and combined effects of heavy metals on vegetable crops, highlighting their complex interactions and impacts (Feng *et al*., 2018; Xie *et al*., 2018).

The present study aimed to quantify the levels of selected heavy metals (Pb, Cd, As, Cr, Cu, Fe, and Zn) in soil and carrot samples, and to evaluate the bioaccumulation factor of these elements in carrots relative to their total concentrations in the soils.

Materials and methods

This study was carried out in 2023 and involved the collection of soil and carrot samples potentially contaminated with heavy metals from six locations in the Republic of Kosovo: Podujevë, Prishtinë, Obiliq, Kishnicë, Mitrovicë, and Shtimje. Soil samples were collected using a manual soil auger, with sampling points positioned at least 10 m away from field boundaries to minimize edge effects. At each site, approximately 2 kg of soil was collected from the top 0–20 cm layer after removing surface vegetation and debris. The samples were placed in clean polyethylene bags for transport. Carrot samples were collected from the same locations, stored in appropriate containers, and labelled according to their respective sampling sites. All samples were clearly coded to ensure traceability. As freshly collected soil samples contained moisture, they were subjected to air-drying or oven-drying immediately after collection to prevent ongoing biological activity and potential compositional changes.

Preparation and preservation of soil and carrot samples

Soil samples were spread evenly on clean paper and dried in an oven at 105°C for three days to ensure complete removal of moisture. After drying, the samples were sieved to eliminate stones, gravel, and plant residues. The fraction passing through a 2 mm sieve was considered as fine earth and retained for further analysis. Carrot samples were thoroughly washed with ultrapure water to remove adhering particles and contaminants. The samples were then dried, and the edible portions were homogenized. The resulting homogenates were stored at 4°C until analysis.

Determination of heavy metal concentrations in soil and carrot samples

Approximately 1 g of each sample (soil and carrot) was subjected to acid digestion using 10 mL of concentrated HNO_3 and 10 mL of concentrated H_2SO_4.

The digestion process was conducted at 400°C for more than one hour. After complete mineralization, the digested samples were diluted with distilled water and filtered through Whatman No. 41 filter paper. The filtrate was transferred into a 50 cm^3 volumetric flask and diluted to volume with distilled water. The concentrations of selected heavy metals in both soil and carrot samples were determined using an Atomic Absorption Spectrophotometer (AAS) (Perkin-Elmer, model 1100, Boston, MA, USA).

Estimation of bioaccumulation factor

The bioaccumulation factor (BAF) was calculated as the ratio between the mean concentration of each heavy metal in carrot samples and the corresponding mean concentration in soil.

Statistical analysis

The obtained data were subjected to statistical analysis using analysis of variance (ANOVA) implemented in the MSTAT-C software package (Michigan University, USA). ANOVA, followed by the least significant difference (LSD) test, was applied to evaluate differences among metal concentrations. Statistical significance was determined at probability levels of $p < 0.05$ and $p < 0.01$.

Results

The findings of the present study regarding the concentrations of selected heavy metals in soil and carrot samples collected from the six investigated locations are presented in Tables 1 and 2.

Table 1. The level of heavy metal presence in soil

Locality	Heavy metal (mg/kg)						
	Pb	Cd	As	Cr	Cu	Fe	Zn
Podujevë	1.03	0.01	0.07	0.54	1.27	173.50	54.68
Prishtinë	0.38	0.05	0.04	0.83	1.53	104.19	32.40
Obiliq	0.44	0.29	0.16	1.15	2.49	176.14	109.15
Kishnicë	2.13	0.50	0.23	3.29	4.72	546.70	185.68
Mitrovicë	6.56	0.79	0.52	2.97	9.10	602.89	397.54
Shtimje	0.27	0.01	0.03	0.30	1.21	58.17	41.36
Average	1.80	0.28	0.17	1.51	3.39	276.93	136.80

The concentration of lead (Pb) in soil samples (Table 1) ranged from 0.27 to 6.56 mg/kg, with an average value of 1.80 mg/kg. In carrot samples, Pb levels were comparatively lower, varying between 0.09 and 3.95 mg/kg, with a mean concentration of 1.06 mg/kg (Table 2). Cadmium (Cd) concentrations in soil varied from 0.01 to 0.79 mg/kg, with a mean of 0.28 mg/kg. In carrots, Cd levels were generally lower, ranging from 0.03 to 0.53 mg/kg, and were not detected in samples collected from Podujevë and Shtimje. Arsenic (As) levels in soil samples ranged from 0.03 to 0.52 mg/kg, with an average of 0.17 mg/kg. Similarly, lower concentrations were observed in carrots, ranging from 0.10 to 0.31 mg/kg, with no detectable levels in samples from Podujevë, Prishtinë, and Shtimje. Chromium (Cr) concentrations in soil ranged between 0.30 and 3.29 mg/kg, with a mean value of 1.51 mg/kg. In carrot samples, Cr levels were lower, ranging from 0.18 to 2.50 mg/kg. Copper (Cu) content in soil samples varied from 1.21 to 9.10 mg/kg, with an average of 3.39 mg/kg. As an essential micronutrient, Cu was present in lower concentrations in carrots, ranging from 0.76 to 5.32 mg/kg. Iron (Fe) concentrations in soil ranged from 58.17 to 602.84 mg/kg, with a mean value of 276.93 mg/kg. In comparison, Fe levels in carrots were lower, ranging from 39.43 to 425.19 mg/kg (Tables 1 and 2). Zinc (Zn) concentrations in soil samples ranged from 41.36 to 397.54 mg/kg, with an average value of 136.80 mg/kg. As with copper, Zn is an essential microelement, and its concentration in carrot samples ranged from 19.65 to 241.32 mg/kg, with a mean of 83.75 mg/kg. Overall, these results indicate that carrots are capable of absorbing and accumulating heavy metals from the soils in which they are cultivated.

Table 2. The concentration of heavy metal in carrots

Locality	**Heavy metal (mg/kg)**						
	Pb	Cd	As	Cr	Cu	Fe	Zn
Podujevë	0.49	ND	ND	0.25	0.86	125.42	36.19
Prishtinë	0.21	0.03	ND	0.61	1.04	78.10	21.13
Obiliq	0.18	0.14	0.10	0.87	1.59	109.25	54.87
Kishnicë	1.30	0.27	0.12	2.50	3.08	377.62	129.10
Mitrovicë	3.95	0.53	0.31	2.13	5.32	425.19	241.32
Shtimje	0.09	ND	ND	0.18	0.76	39.43	19.65
Average	1.06	0.24	0.17	1.09	2.14	194.17	83.75

The bioaccumulation factor (BAF) is defined as the ratio between the concentration of a metal in carrot plants and its corresponding concentration in the soil. Analysis of the BAF values for the studied heavy metals (Table 3) indicates that these factors vary depending on the specific metal.

Table 3. Heavy metals bioaccumulation factor in soil/carrots

Locality	Heavy metal (mg/kg)						
	Pb	Cd	As	Cr	Cu	Fe	Zn
Podujevë	0.48	0.00	0.00	0.46	0.68	0.72	0.66
Prishtinë	0.26	0.60	0.00	0.73	0.70	0.75	0.65
Obiliq	0.43	0.48	0.63	0.76	0.64	0.62	0.50
Kishnicë	0.61	0.54	0.52	0.76	0.65	0.69	0.70
Mitrovicë	0.60	0.67	0.60	0.72	0.58	0.71	0.61
Shtimje	0.33	0.00	0.00	0.60	0.63	0.68	0.48
Average	0.45	0.38	0.29	0.67	0.65	0.70	0.60

The results related to Pb concentrations indicated that the lowest value was recorded in Prishtinë (0.26), whereas the highest was observed in Kishnicë (0.61). For Cd, no detectable levels were found in samples from Prishtinë and Shtimje (0.00), while the highest concentration was measured in Mitrovicë (0.67). Similarly, arsenic (As) was not detected in samples from Podujevë, Prishtinë, and Shtimje, whereas the highest value was recorded in Obiliq. The bioaccumulation factor (BAF) varied among the analyzed metals, as presented in Table 3. On average, the highest BAF value was observed for Fe (0.70), while the lowest was recorded for As (0.29). The remaining metals exhibited intermediate values, specifically 0.67, 0.65, 0.60, 0.45, and 0.38 for Cr, Cu, Zn, Pb, and Cd, respectively. The analysis of variance (ANOVA) results, summarized in Table 4, demonstrated statistically significant differences in heavy metal concentrations across several factors, including locality (Factor A), substrate (Factor B), type of heavy metal (Factor C), as well as their interactions (A×B), (A×C), (B×C), and (A×B×C).

When examining the influence of locality (Factor A), highly significant differences were observed. The average heavy metal content was notably higher in Mitrovicë (121.37 mg/kg) compared to Shtimje, which exhibited the lowest average concentration (11.53 mg/kg) across all metal types. These results indicate that Mitrovicë is the most heavily contaminated site with respect to heavy metals, with statistically significant differences compared to other locations. Regarding the substrate type (Factor B), significant differences were also detected. Soil samples exhibited higher average concentrations of heavy metals (60.13 mg/kg) than carrot samples (40.10 mg/kg), with these differences being highly significant. For the type of heavy metal (Factor C), significant differences were evident as well. Iron (Fe) presented the highest concentration at 234.72 mg/kg, while arsenic (As) showed the lowest concentration at 0.13 mg/kg, and the difference between these two metals was highly significant. The mean concentrations of the other metals were 110.26 mg/kg for zinc (Zn), 2.75 mg/kg for copper (Cu), 1.42 mg/kg for lead (Pb), 1.30 mg/kg for chromium (Cr), and 0.23 mg/kg for cadmium (Cd), with varying levels of statistical significance among them.

Table 4. Heavy metal concentrations (ANOVA)

Locality (A)	Substrate (B)	Heavy metal mg/kg (C)							Average (AxB)	Average (A)
		Pb	Cd	As	Cr	Cu	Fe	Zn		
Podujevë	Soil	1.03	0.01	0.07	0.54	1.27	173.50	54.68	33.01	28.16**
	Carrot	0.49	0.00	0.00	0.25	0.86	125.42	36.19	23.32	
	Average (AxC)	0.76	0.01	0.04	0.40	1.07	149.46	45.44	28.17	
Prishtinë	Soil	0.38	0.05	0.04	0.83	1.53	104.19	32.40	19.92	17.18**
	Carrot	0.21	0.03	0.00	0.61	1.04	78.10	21.13	14.45	
	Average (AxC)	0.30	0.04	0.02	0.72	1.29	91.15	26.77	17.18	
Obiliq	Soil	0.44	0.29	0.16	1.15	2.49	176.14	109.15	41.40	32.63**
	Carrot	0.18	0.14	0.10	0.87	1.59	109.25	54.87	23.86	
	Average (AxC)	0.31	0.22	0.13	1.01	2.04	142.70	82.01	32.63	
Kishnicë	Soil	2.13	0.50	0.23	3.29	4.72	546.70	185.68	106.18	89.80**
	Carrot	1.30	0.27	0.12	2.50	3.08	377.62	129.10	73.43	
	Average (AxC)	1.72	0.39	0.18	2.90	3.90	462.16	157.39	89.81	
Mitrovicë	Soil	6.56	0.79	0.52	2.97	9.10	602.89	397.54	145.77	121.37**
	Carrot	3.95	0.53	0.31	2.13	5.32	425.19	241.32	96.96	
	Average (AxC)	5.26	0.66	0.42	2.55	7.21	514.04	319.43	121.37	
Shtimje	Soil	0.27	0.10	0.03	0.30	1.21	58.17	41.36	14.49	11.53**
	Carrot	0.09	0.00	0.00	0.18	0.76	39.43	19.65	8.59	
	Average (AxC)	0.18	0.05	0.02	0.24	0.99	48.80	30.51	Average B	
Average (BxC)	Soil	1.80	0.29	0.18	1.51	3.39	276.93	136.80	60.13**	
	Carrot	1.04	0.16	0.09	1.09	2.11	192.50	83.81	40.10**	
Average (C)		1.42	0.23	0.13	1.30	2.75	234.72	110.26	Average AxBxC	

Factor		A	B	C	AB	AC	BC	ABC
LSD	1 %	0.664	0.384	0.717	0.939	1.757	1.015	2.485
	5 %	0.505	0.291	0.545	0.714	1.335	0.771	1.888

Legend: Ns = No significant, * = significant, ** = highly significant

Additionally, statistically significant differences were observed in the interactions among the factors (A × B, A × C, B × C, and A × B × C), as presented in Table 4.

Discussion

The results of this study indicate that the bioaccumulation of heavy metals in carrots is strongly influenced by their concentrations in the soil. The observed accumulation pattern in carrot samples largely reflects the mean metal levels in the corresponding soils, with the exception of chromium (Cr), which was detected in higher concentrations than lead (Pb) in carrot tissues. Overall, the accumulation sequence observed was Fe > Zn > Cu > Cr > Pb > Cd > As, which is consistent with findings reported by Ye *et al*. (2015). Similarly, Schiptsova *et al*. (2020) noted that the transfer of heavy metals from soil to carrot plants increases with higher total metal content in the soil, particularly accumulating in the leaves. Recent studies have extensively examined the accumulation of heavy metals in vegetables and their relationship with total and bioavailable fractions in soils (Gupta *et al*., 2022). These investigations reported a significant correlation between soil metal concentrations and their levels in carrot tissues, aligning well with the present findings. Additionally, research by Intawongse and John (2006) demonstrated that, with the exception of lead, concentrations of Cd, Cu, Mn, and Zn in lettuce, spinach, radish, and carrot largely depend on total metal content in the soil. Other studies have confirmed that these metals can be efficiently absorbed by plant roots and accumulate in edible parts, sometimes at elevated levels regardless of soil concentration (Jolly *et al*., 2013). Zinc (Zn) and cadmium (Cd) are particularly mobile and readily taken up by plants (Mench *et al*., 1994). Cadmium, even at low concentrations, is highly toxic and can adversely affect plant growth, biomass, photosynthetic activity, yield, and overall quality (Kumar *et al*., 2016). Copper (Cu), while an essential micronutrient at trace levels, may become toxic to plants when present in excess (Lin *et al*., 2018).

Currently, soil contamination with Cd and Cu is increasing due to excessive use of agrochemicals (Liu *et al*., 2013). Elevated levels of Pb and Cd in food are associated with serious human health risks, including kidney and bone disorders (Jarup, 2003). Moreover, high concentrations of Cu, Pb, and Cd in vegetables have been linked to severe health conditions such as cancer, renal failure, and hypertension (Younas *et al*., 2023).

Iron (Fe), copper (Cu), and zinc (Zn) are essential microelements that serve as vital nutrients for both plants and humans. These elements play key roles in numerous biochemical processes, including chlorophyll synthesis in plants (Erdogan and Demirhan, 2022). In contrast, chromium (Cr) is not an essential element for either plants or humans. Its presence in vegetables is likely linked to prolonged use of inorganic fertilizers and synthetic pesticides in agricultural soils. Accumulation of Cr in humans can contribute to chronic diseases, while in plants, excessive Cr can inhibit growth and adversely affect seed germination (Erdogan and Demirhan, 2022).

Recent studies have focused on the accumulation of heavy metals in plants and their relationship with total and bioavailable fractions in soils (Gupta *et al*., 2022; Plopeanu *et al*., 2023; Samma *et al*., 2024; Ye *et al*., 2015), consistently reporting that metal concentrations in plants are significantly correlated with soil levels. Our results align with these findings. Specifically, bioaccumulation factors (BAFs) for heavy metals in carrots vary by element, with Cd showing the highest accumulation, followed by Zn, Cu, and Pb, which exhibited the lowest uptake (Plopeanu *et al*., 2023). Bioaccumulation factors greater than 1 indicate a high potential for metal accumulation in plants, whereas values below 1 suggest that the plant acts as an excluder (Samma *et al*., 2024; Thornton and Farago, 1997). In this study, all BAF values were below 1, which is consistent with prior research (Gupta *et al*., 2022), indicating limited accumulation of these metals in carrots. According to Ma *et al*. (1983), the level of metal accumulation in carrots is influenced by both the absolute concentration of metals in the soil and the physicochemical interactions within the soil.

Soil and ecosystem contamination with heavy metals represents a major global concern due to the toxic effects of these elements and their ability to bioaccumulate in plants and other organisms, ultimately disrupting the food chain. The present study demonstrates that carrots are capable of accumulating certain metals from the soils of the investigated areas, highlighting their potential use as bioindicators for environmental pollution.

Given that carrots are widely consumed, the transfer of heavy metals through the food chain is possible. Therefore, these findings are valuable for environmental monitoring and risk assessment, supporting the efforts of relevant authorities to ensure food safety and environmental protection in Kosovo.

Acknowledgements

The authors wish to express their sincere gratitude to the Department of Plant Protection at the University of Prishtina for providing access to laboratory facilities and technical support during the course of this study.

Conflicts of interest

The authors declare that there are no conflicts of interest associated with this work.

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(Received: 19 January 2025, Revised: 6 January 2026, Accepted: 10 January 2026)