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**Assessment of Heavy Metal Contamination in
Roadside Soils along Irbid-Amman Highway, Jordan
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Abstract: In this study, the concentrations of selected heavy metals (Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn) in roadside soil samples were determined by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) after microwave digestion. A total of sixty roadside soil samples were collected during July 2018 from seventeen sampling sites (5 km apart) from both sides along Irbid-Amman highway, Jordan. The average concentrations (\pm SD) of the investigated metals in the analyzed soil samples were found to be 18400 (\pm 11200), 6.0 (\pm 4.7), 132 (\pm 47), 49 (\pm 26), 695 (\pm 310), 96 (\pm 53), 78 (\pm 32), 31800 (\pm 12600), 116 (\pm 67), 141 (\pm 74) and 129 (\pm 112) μ g/g for Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn, respectively. With exception of Mn, the enrichment factors for the investigated metals in roadside soils were found to be more than 10, indicating anthropogenic sources such as automobile traffic. In the absence of any industrial activities in the sampling sites, the high concentrations of the investigated metals suggest that automobile emissions are the major source of roadside soil pollution. The results obtained in this study showed that metal concentrations in the analyzed soil samples are strongly influenced by the wind direction and traffic density in the investigated area. The higher metal concentrations on the west side of the road were due to the easterly prevailing wind in the studied area. As expected, the concentrations of heavy metals decreased with increasing distance from the edge of the road. The results obtained in this work were compared with the literature values.

Keywords: Roadside soil, Heavy metals, ICP-OES, Enrichment factor, Irbid-Amman highway, Jordan.

Introduction

Soil is an essential requirement for life as it provides a suitable medium for the growth of plants which are the main source of nutrients, essential minerals and fibers that are useful for human health. Soil supplies plants with essential minerals and nutrients, thereby affecting their nutrition values. However, soil pollution poses a serious threat to human health through polluting the plants, ground water and the atmosphere. Toxic heavy metals, such as Mercury (Hg), Cadmium (Cd), Lead (Pb), Chromium (Cr), Tin (Sn), Nickel (Ni) or Arsenic (As) are hazardous

environmental pollutants that are known to have an adverse impact on human health^[1-5]. On the other hand, other elements like Iron (Fe), Copper (Cu), Zinc (Zn), Selenium (Se), Manganese (Mn), Magnesium (Mg) or Molybdenum (Mo) are important for human health as essential micronutrients and can be toxic if present in excess^[6,7].

Toxic heavy metals are characterized by having a non-biodegradable nature and long biological half-lives^[8-11]. Therefore, they have the tendency to accumulate in different media, such as the human body, soils, surface water,

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plants and foods. Consequently, they can impair normal development and important biochemical processes, leading to harmful effects on human health^[3,6,12-14]. In recent years, human exposure to heavy metals has largely increased as a result of using these metals as raw materials in different industries as well as due to rapid industrialization and urbanization^[14-16].

During the last years, soil pollution due to toxic heavy metals has attracted increasing attention as a serious worldwide health and environmental problem^[12,14,16]. Several environmental studies have shown that the major sources of soil contamination by heavy metals are irrigation with contaminated water (municipal and industrial waste water), vehicular emissions, disposal of industrial wastes, agricultural activities, mining activities, fossil fuel combustion, wear of brake lining materials, road paint degradation, repair of damaged roads, as well as the application of large quantities of chemical fertilizers and metal-based pesticides^[14,16-25].

In urbanized areas, atmospheric deposition due to vehicular emissions and traffic activities is the major source of heavy metal pollution^[21,24,26,27]. Generally, heavy metals can accumulate on surface soils through atmospheric deposition by sedimentation, impaction and interception^[17,21,24]. Consequently, roadside soils, street dust and plants grown near major highways could receive significant amounts of toxic heavy metals and can thus be used as a useful indicator of heavy metal pollution in urbanized areas. In this context, several metals are known to be directly related to road traffic, such as Cu, Zn, Pb, Cd, Cr, Co, Ni, As, Ba, Sb, Mn, V, Pt, Pb and Rh^[16,21,22,28]. Of these, Pb, Cd, Cr, Cu, Co and Zn are the major metal pollutants of the roadside environments, originating from the combustion of leaded fuel, wearing out of car tires, oil leakage and corrosion of batteries^[12,21,23].

In Jordan, several environmental studies have been performed to investigate heavy metal pollution in a wide variety of environmental samples, such as roadside soils, street dust, plants, air and agriculture soils^[6,9,10,17-19,22-24,28-34]. Most of these studies confirmed that the anthropogenic activities (e.g. automobile emissions, smelting, burning of fossil fuels, mining, application of insecticides, wastewater, industries and agricultural activities) are the major contributors to heavy metal pollution in the investigated samples. There is, however,

limited information available on the contamination levels of heavy metals in roadside soils along Irbid-Amman highway, which could give important information about the safeness of these soils for farming purposes. To the best of the authors' knowledge, this is the first study of its kind to investigate the concentrations of heavy metals in roadside soils along Irbid-Amman highway, Jordan. The main objectives of the present study were: (i) to determine the concentrations of 11 heavy metals (Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn) in roadside soils collected from various sampling sites along Irbid-Amman highway, Jordan, (ii) to study the distribution of these metals in roadside soils within the study area and (iii) to define the possible sources of these metals.

Materials and Methods

Study Area

The study area is located in the northern side of Amman, the capital of Jordan. The total length of the selected route is approximately 80 km (Figure 1). Irbid-Amman highway is characterized by heavy traffic density over the daily 24 hours. Seventeen sampling sites (5 km apart) were selected along this highway. The sampling sites cover the distance from Irbid-Amman transit bus station, Irbid (Site A1) to the north terminal, Amman (Site A17) (Figure 1). The sampling sites A2-A4 represent an urban area (Al Husun city, 35,000 inhabitants, 65 km north of Amman) with high traffic volume, garage repairs, wear of brake lining and gas stations. Sampling sites A5-A16, represent a rural area in which natural landscapes, such as mountains, are the main topographic characteristics. The traffic volume in these sites is relatively high. It must be noted that no industrial activities exist along Irbid-Amman highway and the proportion of agricultural land use is relatively small. Thus, traffic emissions are the only contamination source of heavy metals in the investigated area.

Chemicals and Reagents

All chemicals and reagents used in this study were of analytical grade. A multi-element standard solution of 1000 ppm (mg/L) of each tested element, including Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn (analytical grade), was obtained from Merck KGaA, Darmstadt, Germany. Nitric acid (HNO₃, 70% v:v, extra pure-trace analysis grade) was obtained from Carlo Erba Reagents, France. Hydrogen peroxide

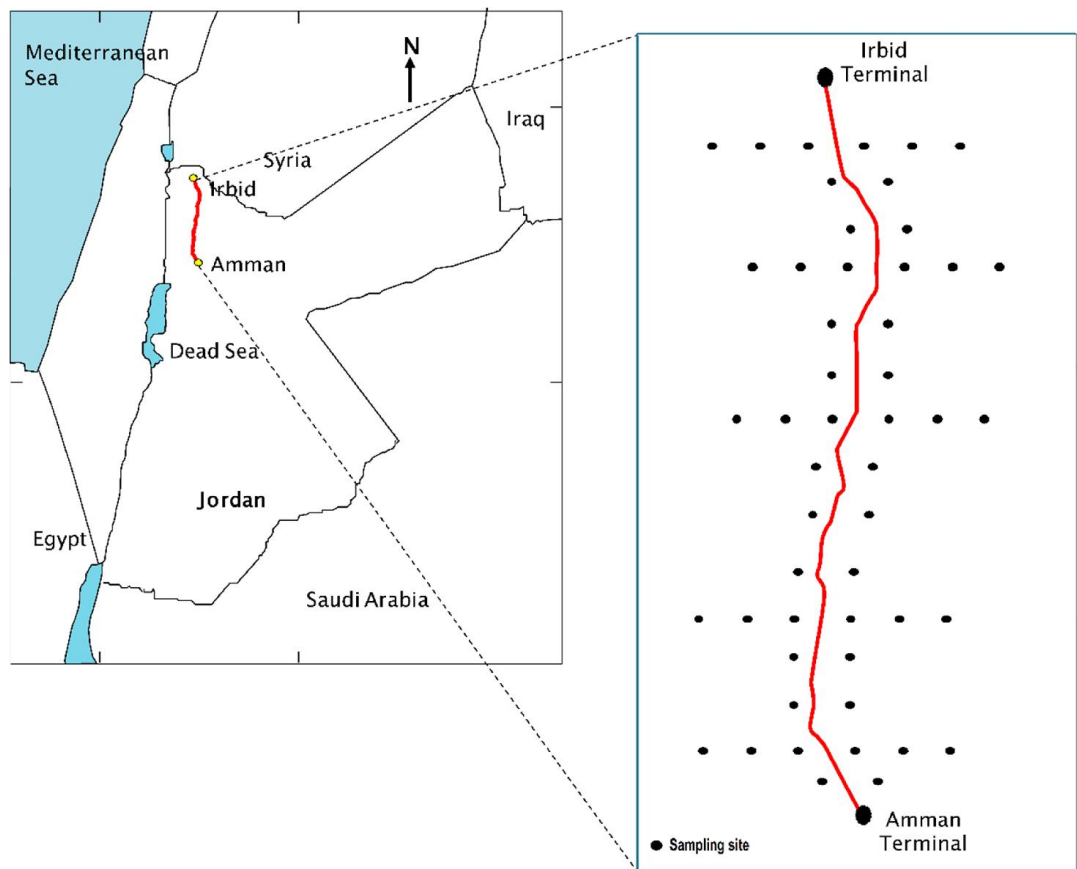


Figure 1. Study area and sampling sites along Irbid-Amman highway, Jordan.

(H_2O_2 , 35% w:w, extra pure) and hydrochloric acid (HCl, 35-38% v:v, high purity analytical grade) were obtained from Scharlau Chemie, Barcelona, Spain. Ultrapure deionized water was used to prepare standard and sample solutions.

Sample Collection and Pretreatment

A total of sixty roadside surface soil samples (the upper 2-3 cm) were collected during the dry season in July 2018. At each sampling site, samples were collected at different distances from the edge of Irbid-Amman highway (1, 50 and 100 m) on both sides (east and west). Roadside soil samples were collected using a plastic dustpan and clean brush. Samples were collected in dried polyethylene bags and prepared in a clean laboratory. Samples were then sieved through 2-mm mesh plastic sieve to remove large impurities, such as stones, glasses, cigarettes, wires, plastic pieces and plant roots. The sieved samples were dried at 85 °C for about 24 hours to a constant weight. The dried samples were then homogenized and ground using a mortar and pestle and stored in clean dry air-

tight polyethylene bags until analysis. A trace element grade nitric acid (70% supra-pure HNO_3), hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2) were used for digestion and solution preparation. All glassware apparatuses were effectively cleaned and previously soaked in 20% (v/v) HNO_3 for 24 hours and then rinsed with deionized water prior to use.

Digestion Procedure

In this study, a microwave digestion system (Anton Paar, Multiwave Eco.) was used to extract metal ions from the roadside soil samples. Amounts of 0.3-0.4 g of each homogenized soil sample were accurately weighed and transferred into a labelled microwave Teflon vessel. To each vessel, 9 mL of redistilled concentrated nitric acid (70% supra-pure HNO_3), 3 mL HCl and 2 mL H_2O_2 were then added. The mixture was allowed to stand in the vessel for 10 minutes prior to sealing. The microwave was operated at a power of 850 watts and the vessels were heated to 200 °C over 10 minutes and then held at 200 °C for

10 minutes. At the end of the digestion procedure, the solutions were filtered and quantitatively transferred into 50 mL volumetric flasks and brought to volume with deionized water. Each extract solution was analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES).

Instrumentation

Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES) (Model: Varian, Vista-MPX, CCD simultaneous ICP-OES, nebulizer type: glass concentric with pressure of 200 kPa) equipped with a 1.4 kW power and axially viewed argon plasma was used to determine the concentrations of the studied heavy metals (Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn) in the analyzed soil samples. The following experimental conditions were used during the analysis: plasma argon flow rate of 13 L/min, auxiliary argon flow rate of 0.5 L/min, nebulizer argon flow rate of 0.5 L/min, integration time of 100 seconds, read delay of 25 seconds and peristaltic pump flow rate of 1.0 mL/min. Analysis using ICP-OES was carried out at the most sensitive wavelength of the examined metals, as shown in Table 1.

Table 1. Wavelength of detection (nm), limit of detection (LOD), limit of quantitation (LOQ), and correlation coefficient (R^2) of each metal.

Element	Wavelength (nm)	LOD ($\mu\text{g/g}$)	LOQ ($\mu\text{g/g}$)	R^2
Al	396.152	15	50	0.990
Cd	214.439	0.5	1.7	0.996
Cr	267.716	2.5	8.3	0.992
Cu	327.395	3.0	10	0.991
Mn	257.61	4.0	13.3	0.993
Pb	220.353	3.0	10	0.995
Co	238.892	2.0	6.7	0.998
Fe	238.204	2.5	8.3	0.997
Ni	231.604	3.0	10	0.999
V	292.401	0.5	1.7	0.996
Zn	213.857	1.5	5.0	0.991

Calibration

The working standard solutions of each studied metal were freshly prepared by diluting an appropriate aliquot of standard solution (1000 mg/L) using 0.5% (v:v) HNO_3 . From the linear calibration curve, the limit of detection LOD ($\mu\text{g/g}$) and limit of quantitation LOQ ($\mu\text{g/g}$) were estimated using the following equations^[1]:

$$\text{LOD} = \frac{3 \times S_a}{m} \quad (1)$$

$$\text{LOQ} = \frac{10 \times S_a}{m} \quad (2)$$

where S_a is the standard error of y-intercept of regression line and m is the slope of the calibration curve.

Quality Control and Assurance

In order to confirm the accuracy and reliability of the instrumental method used for the analysis of the investigated heavy metals in the roadside soil samples investigated in this study, a quality assurance program was employed and standard reference materials for these metals were analyzed. In this context, two standard reference materials, SRM-2704 (Buffalo river sediment) and SRM-2710 (Montana soil) were digested in the same manner as for original soil samples and analyzed along with soil samples. The results indicated that the measured values for the examined metals are in good agreement (> 90%) with their certified values provided by the National Institute of Standards and Technology (NIST). The percentage recovery of the various metals of interest in the (SRM-2704) reference material was found to be: Al (94%), Cd (99%), Co (95%), Cr (97%), Cu (93%), V (90%), Mn (98%), Ni (94%), Pb (96%), Fe (96%) and Zn (98%), whereas the corresponding percentage recoveries for the SRM-2710 reference material were: Al (96%), Cd (98%), Co (93%), Cr (97%), Cu (96%), Ni (93%), Pb (95%), V (94%), Mn (92%), Fe (97%) and Zn (98%). These findings confirm good accuracy and validity of the ICP-OES analysis method used for the determination of metal concentrations in the investigated soil samples. In addition, reagent blanks and duplicate samples were used during the analysis to confirm the precision of the obtained results.

Results and Discussion

Limit of Detection and Limit of Quantitation

The detection limits (LOD and LOQ) obtained for each metal are listed in Table 1. The calibration curves of the investigated metals were linear with correlation coefficients, $R^2 > 0.99$ (Table 1). The detection limit values of the tested metals ranged between 0.5 $\mu\text{g/g}$ for Cd and 15 $\mu\text{g/g}$ for Al, while LOQ ranged between 1.7 $\mu\text{g/g}$ and 50 $\mu\text{g/g}$ for the same metals

(Table 1). The relatively low values of the detection limits (LOD and LOQ) demonstrate the sensitivity of ICP-OES method used for the metal analysis in the investigated roadside soil samples.

Metal Concentrations in Roadside Soils

Table 2 presents the concentrations (mean \pm SD) of the eleven heavy metals studied in this work in the roadside surface soil along Irbid-Amman highway. All heavy metal concentrations were determined on a dry-weight basis. The average concentrations of the studied metals were found to be in the range of 7350-51300 (Al), 1-19 (Cd), 61-234 (Cr), 5-103 (Cu), 73-1350 (Mn), 35-206 (Pb), 23-147 (Co), 9470-65200 (Fe), 32-217 (Ni), 31-288 (V) and 34-419 (Zn) $\mu\text{g/g}$ (Table 2). The average metal concentrations ($\mu\text{g/g}$) are in the following order for the soil samples: Fe > Al > Mn > V > Cr > Zn > Ni > Pb > Co > Cu > Cd.

As a general trend, there is a clear increase in metal concentrations in bus terminals (sampling sites A1 and A17) as well as in sites with increased traffic density. For example, the results in Table 2 show that metal concentrations increase significantly in the sampling sites A1-A6. These sampling sites are urbanized areas with high traffic volume, garage repairs and intense residential places. Moreover, the

sampling sites A16 and A17 exhibited high contamination levels of the examined metals. These sites are also urbanized areas with extremely high traffic density over 24 hours.

In this study, the results showed that the average Cd concentrations found in the analyzed soil samples ranged from 1 to 19 $\mu\text{g/g}$ with a mean of 6.0 $\mu\text{g/g}$ (Table 2). According to the Dutch standards and FAO/WHO (Food and Agriculture Organization/World Health), the maximum Cd levels permitted in soil are 0.8 and 3 $\mu\text{g/g}$, respectively^[35,36]. These findings indicate that the average concentrations obtained for Cd in the most of the analyzed soil samples were found to be above the prohibited limits for this metal. The results show that the highest Cd concentration was found at sampling site A5, which was also heavily polluted with Pb, Cr, Mn and Zn (Table 2, Figure 2). Cd is mainly derived from tire rubber, engine oil, and abrasion of brake linings^[21,30]. In the absence of industrial activities in the sampling sites, the high concentrations of Cd found in the investigated soil samples might be due to lubricating oils and old car tires. The average Cd concentration found in this study is much higher than those reported by other researchers^[12,37-41], but it is still lower than those found in Jordan^[28] as shown in Table 3.

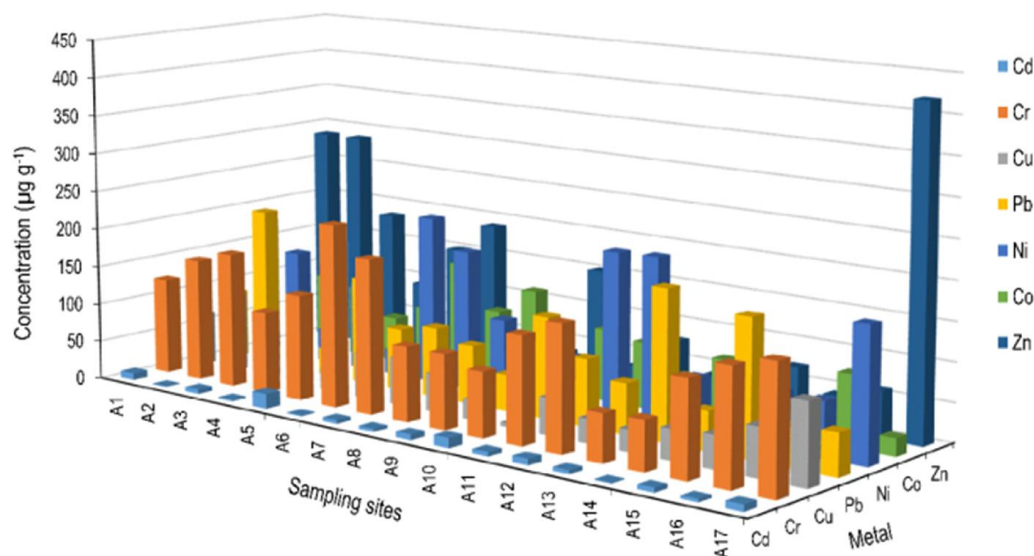


Figure 2. Average concentrations of Cd, Cr, Cu, Pb, Ni, Zn and Co in roadside soils collected from various sampling sites (A1-A17) along Irbid-Amman highway, Jordan.

Table 2. Average concentrations, standard deviation (SD), coefficient of variation (CV) and concentration range of Al, Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn ($\mu\text{g/g}$) in roadside soils along Irbid-Amman highway, Jordan.

Sampling site	Al	Cd	Cr	Cu	Mn	Pb	Co	Fe	Ni	V	Zn
A1 (Irbid terminal)	7350	9	125	68	365	89	81	22300	179	258	286
A2	20700	1	158	102	984	206	99	39000	141	34	286
A3	51300	6	174	55	1350	77	91	65200	42	130	183
A4	15900	2	105	31	1040	35	58	35300	114	237	95
A5	19900	19	136	28	1040	138	79	41500	32	134	150
A6	37100	1	234	58	883	80	147	46600	217	116	189
A7	14600	5	198	60	657	90	92	23800	180	106	44
A8	9500	4	96	49	435	76	127	16000	99	160	36
A9	8100	7	96	25	73	47	26	9470	68	126	152
A10	19400	13	83	5	518	130	93	27600	67	111	34
A11	18300	6	137	47	484	86	85	25400	210	171	77
A12	20900	8	160	31	638	65	51	32600	212	103	40
A13	21700	5	61	28	792	191	81	37100	70	78	34
A14	16200	1	63	39	626	50	57	32200	32	288	70
A15	14400	6	122	42	495	173	48	25200	71	31	43
A16	9200	4	146	62	902	50	91	32400	70	225	59
A17 (Amman terminal)	8100	9	160	103	531	54	23	29500	171	91	419
Average	18400	6	132	49	695	96	78	31800	116	141	129
SD	11200	5	47	26	310	53	32	12600	67	74	112
CV	61	77	35	53	45	55	41	40	58	52	87
Range	7350-51300	1-19	61-234	5-103	73-1350	35-206	23-147	9470-65200	32-217	31-288	34-419

Table 3. Average concentrations of Cd, Cr, Cu, Pb, Ni, Co, Zn and Mn ($\mu\text{g/g}$) in roadside soils along Irbid-Amman highway compared with other studies in different countries in the world.

Country	Cd	Cr	Cu	Pb	Ni	Co	Zn	Mn	Ref.
Jordan	9	--	--	70	56	32	113	--	[28]
Nigeria	0.79	--	6.24	4.74	0.63	--	79.24	8.12	[37]
United Arab Emirates	0.17-1.01	--	15.51 - 65.90	259.66 - 2784.45	13.31 - 98.13	--	91.34 - 166.43	57.95 - 166.4	[12]
China	0.22	61.9	29.7	35.4	26.7	--	92.1	--	[38]
England	1.40	--	87.3	232.7	--	--	174.6	--	[39]
Pakistan	0.84	--	12.98	36.46	8.82	5.95	56.72	174.09	[40]
Turkey	2.32	--	122.37	185.84	30	--	447.72	395	[41]
Jordan/(Irbid-Amman highway)	6	132	49	96	116	78	129	695	This study

According to the data presented in Table 2, the average concentrations obtained for Cr in the analyzed soil samples ranged from 61 to 234 $\mu\text{g/g}$ with a mean of 132 $\mu\text{g/g}$. According to the Dutch standards and WHO/FAO, the maximum Cr level permitted in soil is 100 $\mu\text{g/g}$ ^[35,36]. The results in Table 2 show that in general, the Cr concentrations found in the analyzed samples, except those collected from the sampling sites A8-A10, A12 and A14, were higher than the permissible levels set by various health organizations (Table 2). The highest Cr concentration was found at sampling site A6, where Co and Ni were also at maximum (Table 2, Figure 2). The average Cr concentration found in this study is much higher than those found in China^[38] (Table 3). The elevated levels of Cr found in the analyzed soil samples might be due to brake linings, engine oil, and road abrasion^[21].

The average Cu concentrations found in the analyzed soil samples ranged from 5 to 103 $\mu\text{g/g}$ with a mean of 49 $\mu\text{g/g}$ (Table 2). The permissible Cu limit recommended by Dutch standards is 36 $\mu\text{g/g}$ ^[35], while WHO/FAO sets this level at 100 $\mu\text{g/g}$ ^[36]. According to the data presented in Table 2, the average Cu concentrations in the soil samples analyzed in this study were found to be within the permissible limits set by these health organizations. The highest Cu concentration was found at sampling site A17 with a mean of 103 $\mu\text{g/g}$ (Table 2, Figure 2). This is expected, because sampling site A17 is the north bus terminal in Amman. The high Cu concentrations

found in the analyzed soil samples could be due to engine wear, tearing of car tires, bushing and bearing metals^[21,23,30]. The average Cu concentration determined in this study was higher than those found in Nigeria^[37], China^[38] and Pakistan^[40], but it is still lower than those found in the United Arab Emirates^[12], England^[39] and Turkey^[41] (Table 3).

According to the data listed in Table 2, the average Pb concentrations found in the analyzed soil samples ranged from 35 to 206 $\mu\text{g/g}$ with a mean of 96 $\mu\text{g/g}$. The maximum Pb concentration permitted in soil is 85 $\mu\text{g/g}$ according to the Dutch standards and 50 $\mu\text{g/g}$ according to WHO/FAO^[35,36]. This implies that the average concentrations obtained for Pb in the analyzed soil samples, except those in the soil samples collected from sampling sites A4 and A9 were found to be above the permitted limits for this metal. The highest Pb concentration was found at sampling site A2 with a mean of 206 $\mu\text{g/g}$ (Table 2, Figure 2). This is expected, because sampling site A2 is an urban area with high traffic volume. Pb is mostly originated from the combustion of leaded fuel^[24,30]. In addition, Pb can be derived from tires, brakes and the road paints^[21]. Since no industrial activities exist along Irbid-Amman highway, the high Pb concentrations found in the investigated soil samples could be due to vehicular emissions^[23]. The average concentration of Pb determined in this study was, however, higher than those found in Jordan^[28], Nigeria^[37], China^[38] and Pakistan^[40], but it is lower than those found in the United Arab Emirates^[12], England^[39] and Turkey^[41] (Table 3).

For the concentrations of Ni in the investigated soil samples, the results show that the average Ni concentrations ranged from 32 to 217 $\mu\text{g/g}$ with a mean of 116 $\mu\text{g/g}$ (Table 2). The maximum Ni concentration permitted in soil is 35 $\mu\text{g/g}$ according to the Dutch standards and 50 $\mu\text{g/g}$ according to WHO/FAO^[35,36]. These findings reveal that the average Ni concentrations found in the analyzed soil samples, except those in the soil samples collected from sampling sites A5 and A14, generally exceeded the permissible limits set by these health organizations. The highest Ni concentration was found at sampling site A6, where Co and Cr were also at maximum (Table 2, Figure 2). The elevated levels of Ni in the analyzed soil samples might be attributed to engine oil leakage, tire wear and road abrasion^[21]. The average concentration of Ni determined in this study was much higher than those found by other researchers^[12,28,37,38,40,41] as shown in Table 3.

The average Zn concentrations detected in the analyzed soil samples ranged from 34 to 419 $\mu\text{g/g}$ with a mean of 129 $\mu\text{g/g}$ (Table 2). According to the Dutch and WHO/FAO standards, the maximum Zn concentrations permitted in soil are 140 $\mu\text{g/g}$ and 300 $\mu\text{g/g}$, respectively^[35,36]. With the exception of the soils collected from sampling site A17, the average concentrations obtained for Zn in the analyzed soil samples in this study were found to be within the permissible limits for this metal as shown in Table 2 and Figure 2. The highest Zn concentration was found at sampling site A17 with a mean of 419 $\mu\text{g/g}$ (Table 2, Figure 2). Sampling site A17 represents the north bus terminal in Amman city with high traffic volume over 24 hours. In the absence of industrial activities along Irbid-Amman highway, the elevated levels of Zn found in the soil samples might be due to the mechanical abrasion of brake linings, tearing of motor vehicle tires rubber and lubricating oils^[21,23]. The average Zn concentration determined in this study was higher than those found in Jordan^[28], Nigeria^[37], China^[38] and Pakistan^[40], but it is lower than those found in the United Arab Emirates^[12], England^[39] and Turkey^[41] (Table 3).

The average concentrations obtained for Cobalt (Co) in the soil samples analyzed in this study ranged from 23 to 147 $\mu\text{g/g}$ with a mean of 78 $\mu\text{g/g}$ (Table 2). According to the Dutch standards, the maximum Co concentration permitted in soil is 9.0 $\mu\text{g/g}$ ^[35]. This means that the average Co concentrations found in the analyzed soil samples were found to be above the permitted limits for this metal. The highest Co concentration was found at sampling site A6 which is also rich in Cr and Ni (Table 2, Figure 2). The average Co concentration obtained in this study was much higher than those found in Jordan^[28] and Pakistan^[40] (Table 3). One possible reason for the high concentrations obtained for Co in the analyzed soil samples is the tearing of motor vehicle tires^[21].

The average concentrations for Aluminum (Al), Manganese (Mn) and Vanadium (V) in the analyzed soil samples ranged from 7350-51300, 73-1350 and 31-288 $\mu\text{g/g}$, respectively (Table 2). The high concentrations of these metals in the analyzed soil samples can be attributed to heavy traffic on the investigated road.

Enrichment Factor

In order to estimate whether the origin of heavy metal pollution in the analyzed soil samples is due to anthropogenic or natural origin, the enrichment factor (EF) for the investigated metals was calculated (Table 4). The enrichment factor (EF) for a given metal is commonly used to estimate the degree of anthropogenic pollution based on the normalization of the concentration of the studied metal in the soil samples against crustal metals such as Fe, Mn or Al^[42,43]. The enrichment factor (EF) for a given metal is calculated using the following equation^[42]:

$$EF = \frac{[M]_{\text{Sample}}/[Al]_{\text{Sample}}}{[M]_{\text{Crust}}/[Al]_{\text{Crust}}} \quad (3)$$

where $[M]_{\text{sample}}$ is the concentration of the metal in a soil sample, $[Al]_{\text{sample}}$ is the concentration of Al in a soil sample, $[M]_{\text{Crust}}$ is the concentration of the metal in earth crust, and $[Al]_{\text{Crust}}$ is the concentration of Al in earth crust. In this study, average metal concentrations ($[M]_{\text{Crust}}$) of the upper continental crust were taken from Taylor and McLennan^[44].

Table 4. Enrichment factors (EFs) of Cd, Cr, Cu, Mn, Pb, Co, V, Ni and Zn in roadside soils along Irbid-Amman highway, Jordan.

Sampling site	Cd	Cr	Cu	Mn	Pb	Co	V	Ni	Zn
A1 (Irbid terminal)	1000	39	30	7	49	89	47	98	44
A2	40	18	16	6	40	38	2	27	16
A3	96	8	3	4	6	14	3	3	4
A4	103	15	6	9	9	29	20	29	7
A5	784	16	5	7	28	32	9	6	9
A6	22	14	5	3	9	32	4	24	6
A7	281	31	13	6	25	51	10	50	3
A8	345	23	17	6	32	107	23	42	4
A9	706	27	10	1	23	26	21	34	21
A10	548	10	1	4	27	38	8	14	2
A11	270	17	8	4	19	37	13	46	5
A12	313	18	5	4	12	20	7	41	2
A13	189	6	4	5	35	30	5	13	2
A14	51	9	8	5	12	28	24	8	5
A15	341	19	9	5	48	27	3	20	3
A16	355	36	22	13	22	79	33	30	7
A17 (Amman terminal)	914	45	41	9	27	23	15	85	59

Zhang and Liu reported that EF values from 0.5 to 1.5 are an indication of that the metal is derived from crustal contribution, while values greater than 1.5 suggest that the metal source might be related to anthropogenic activities^[43]. According to Alsou and Al-Khashman, three contamination levels are classified based on EF values: (i) low enrichment factor ($EF < 10$), (ii) medium enrichment factor ($10 \leq EF \leq 100$) and (iii) high enrichment factor ($EF > 100$)^[18].

In this work, enrichment factors for the selected metals (Cd, Cr, Cu, Mn, Pb, Co, V, Ni and Zn) were calculated and listed in Table 4. According to this data, the highest enrichments for all investigated metals were obtained for the soil samples collected from the bus terminals (sampling sites A1 and A17). In the absence of any industrial activities in these sampling sites, the major source of these metals is mainly due to traffic. In addition, the average values of the enrichment factors for the investigated metals

were found to decrease in the following order: Cd > Co > Ni > Pb > Cr > V > Cu > Zn > Mn (Table 4).

The results in Table 4 show that Cd has an extremely high enrichment factor (ranging from 22 to 1000) in the most sampling sites. These findings clearly indicate that the origin of this metal in the analyzed soil samples is due to anthropogenic sources such as traffic emissions, tire rubber, engine oil leakage, fertilizers, pesticides and abrasion of brake linings^[21,23,30]. However, Cd in sampling sites A2, A3, A6 and A14 showed medium enrichment factors ($10 \leq EF \leq 100$).

The data presented in Table 4 show that Cr, Cu, Co, Pb, Ni, V and Zn have medium enrichment factors in most of the sampling sites, which confirms the presence of a significant contamination due to anthropogenic sources. However, Zn and Cu exhibited low enrichment factors in sampling sites A3-A8 and A10-A16,

which indicates that these sampling sites are less affected by anthropogenic activities (Table 4). On the other hand, Mn showed low enrichment factors in all of the sampling sites with values lower than 10, as illustrated in Table 4. The results suggest that the origin of this metal in the sampling sites is mostly due to the natural processes.

Variation of Distance from Roadside

The atmospheric deposition of heavy metals onto roadside soils is influenced by several

factors that affect their accumulation such as traffic volume, distance from roadside, width of road, nature of soil, size of soil particles, wind speed and direction, land terrain, land cover and altitude as well as road surface material^[21,22,34]. In the present study, the average concentrations of the metals of interest were determined in roadside soil samples collected from sampling site A5 at varied distances (1, 50 and 100 m) from the east (left) and west (right) of the main road edge (Table 5).

Table 5. Average concentrations of Cd, Cr, Cu, Mn, Pb, Co, Fe, Ni, V and Zn ($\mu\text{g/g}$) in roadside soils collected from both sides of sampling site A5 at varied distances (1, 50 and 100 m).

Distance/ (m)	Cd	Cr	Cu	Mn	Pb	Co	Fe	Ni	V	Zn
1-m W	28	475	73	973	190	21	70800	102	118	448
50-m W	21	279	92	1080	142	67	52000	81	345	263
100-m W	2	188	52	1090	33	93	48600	35	17	183
1-m E	7	187	50	1310	133	74	58200	140	532	122
50-m E	0.5	173	52	1130	95	74	52000	143	256	108
100-m E	0.5	167	31	1140	30	61	51100	116	97	60

*W: West of the roadside (Right); *E: East of the roadside (Left).

As a general trend, metal concentrations decrease with increasing distance from the edge of the road, which indicates that the accumulation of metals in the studied soil samples was mainly due to the pollution from automobile emissions. In this context, many researchers have reported that the concentrations of heavy metals decrease with increased distance from the roadside^[21,23,30]. In addition, it was observed that higher metal concentrations were found in the soil samples collected from the west of the road than those found in the east of the road (Table 5). These findings can be attributed to the easterly prevailing winds in the investigated sampling sites.

Conclusions

The results obtained in this study revealed the presence of a significant accumulation of traffic-related heavy metals (Al, Cd, Cr, Cu, Pb, Co, Fe, Ni, Mn, V and Zn) in roadside soils from Irbid-Amman highway, Jordan. The average concentrations of these metals in the analyzed soil samples were found to be above the permissible limits for these metals set by health organizations (e.g. FAO/WHO and Dutch standards^[35,36]). The results showed that metal concentrations in the analyzed soil samples

decrease as the distance increases from both roadsides (east and west). However, higher metal concentrations were observed on the west side of the road, due to the dominant easterly wind direction in the investigated area. The investigated metals were found to be highly enriched in the soil samples collected from the bus terminals (sampling sites A1 and A17), indicating anthropogenic sources, such as automobile emissions. Since no industrial activities exist along Irbid-Amman highway, the distribution of metal concentrations in the soil samples indicates that automobile traffic is the major source of heavy metal contamination in the soil along Irbid-Amman highway. The elevated levels of toxic heavy metals in roadside soils need to be monitored regularly for heavy metal enrichment.

Acknowledgement

The authors thank Al al-Bayt University (Mafraq, Jordan) and Yarmouk University (Irbid, Jordan) for providing the required facilities to perform this work and carry out the ICP-OES analysis on the soil samples.

Disclosure Statement

Conflict of interests: The authors declare that they have no conflict of interests.

References

- [1] Al-Massaedh, A. A.; Gharibeh, A.; Radaydeh, S.; Al-Momani, I., *Eur. J. Chem.*, **2018**, *9* (4), 395-400.
- [2] Massadeh, A. M.; Al-Massaedh, A. A.; Kharibeh, S., *Environ. Sci. Pollut. Res.*, **2018**, *25*, 3501-3509.
- [3] Massadeh, A.; Gharibeh, A.; Omari, K.; Al-Momani, I. F.; Alomari, A.; Tumah, H.; Hayajneh, W., *Biol. Trace Elem. Res.*, **2010**, *133* (1), 1-11.
- [4] Alomary, A.; Al-Momani, I. F.; Massadeh, A. M., *Sci. Total Environ.*, **2006**, *369*, 69-75.
- [5] Shaheen, N.; Irfan, N. M.; Khan, I. N.; Islam, S.; Islam, M. S.; Ahmed, M. K., *Chemosphere*, **2016**, *152*: 431-438.
- [6] Alomary, A.; Jamal, E. E.; Al-Momani, I. F.; Attiyat, A.; Obeidat, S., *Environ. Chem. Lett.*, **2013**, *11* (1), 55-63.
- [7] Alzahrani, H. R.; Kumakli, H.; Ampiah, E.; Mehari, T.; Thornton, A. J.; Babyak, C. M.; Fakayode, S. O., *Arabian J. Chem.*, **2017**, *10* (7), 906-913.
- [8] Massadeh, A. M.; Al-Massaedh, A. A., *Environ. Sci. Pollut. Res.*, **2018**, *25*, 1914-1920.
- [9] Batayneh, A. T.; Al-Momani, I. F.; Jaradat, R. A.; Awawdeh, M. M.; Rawashdeh, A. M.; Ta'any, R. A., *J. Environ. Hydrol.*, **2008**, *6* (20), 1-11.
- [10] Al-Momani, K.; Jaradat, Q.; Jbarah, A.; Al-Momani, I. F., *Abhath Al-Yarmouk*, **2003**, *12* (2B), 503-511.
- [11] Belay, K.; Abisa, Z., *Int. J. Chem. Nat. Sci.*, **2015**, *3* (1): 195-199.
- [12] Aslam, J.; Khan, S. A.; Khan, S. H., *J. Saudi Chem. Soc.*, **2013**, *17* (3), 315-319.
- [13] Al-Momani, I. F.; Al-Rawi, Z. R.; Salameh, A. M.; Bataineh, Q., *Abhath Al-Yarmouk*, **2005**, *14* (2), 217-227.
- [14] Wuana, R. A.; Okieimen, F. E., *International Scholarly Research Network (ISRN Ecology)*, **2011**, *11*, 1-19.
- [15] Al-Thagafi, Z.; Arida, H.; Hassan, R., *Int. J. Innov. Res. Sci. Eng. Technol.*, **2014**, *3* (2), 8977-8989.
- [16] Su, C.; Jiang, L.; Zhang, W., *Environ. Skep. Crit.*, **2014**, *3* (2), 24-38.
- [17] Al-Momani, I. F. *Soil Sediment Contam.*, **2007**, *16* (5), 485-496.
- [18] Alsbou, E. M. E.; Al-Khashman, O. A., *Environ. Monit. Assess.*, **2018**, *190* (1), 48.
- [19] Al-Khashman, O. A.; Shawabkeh, R. A., *Environ. Pollut.*, **2006**, *140*, 387-394.
- [20] Al-Momani, I. F.; Shatnawi, W. M., *Int. J. Environ. Monit. Anal.*, **2017**, *5* (4), 103-108.
- [21] Wang, G.; Zeng, C.; Zhang, F.; Zhang, Y.; Scott, C. A.; Yan, X., *Sci. Total Environ.*, **2017**, *581-582*, 811-821.
- [22] Massadeh, A. M.; Tahat, M.; Jaradat, Q.; Al-Momani, I. F., *Soil Sediment Contam.*, **2004**, *13*, 347-359.
- [23] Jaradat, Q. M.; Momani, K. A., *Turk. J. Chem.*, **1999**, *23*, 209-220.
- [24] Al-Momani, I. F., *Jordan J. Chem.*, **2009**, *4* (1), 77-87.
- [25] Arora, M.; Bala, K.; Rani, S.; Rani, A.; Kaur, B.; Mittal, N., *Food Chem.*, **2008**, *111* (4), 811-815.
- [26] Wang, M.; Zhang, H., *Int. J. Environ. Res. Public Health*, **2018**, *15* (6), 1064-1074.
- [27] Al-Momani, I. F., *Atmos. Environ.*, **2003**, *37*, 4507-4515.
- [28] Howari, F. M.; Abu-Rukah, Y.; Goodell, P. C., *Int. J. Environ. Pollut.*, **2004**, *22* (5), 597-607.
- [29] El-Rjoob, A.A.O.; Omari, M. N., *J. Int. Environ. Appl. Sci.*, **2009**, *4* (4), 433-441.
- [30] Jaradat, Q.; Al-Momani, K.; Jiries, A. G.; El-Alali, A.; Batarseh, M.; Sabri, T. G.; Al-Momani, I. F., *Water, Air, Soil Pollut.*, **1999**, *112*, 55-65.
- [31] Al-Khashman, O. A., *Atmos. Environ.*, **2004**, *38*, 6803-6812.
- [32] Banat, K. M.; Howari, F. M.; Al-Hamad, A. A., *Environ. Res.*, **2005**, *97* (3), 258-273.

- [33] Al-Momani, I. F.; Daradkeh, A. S.; Haj-Hussien, A.; Yousef, A.; Jaradat, Q.; Al-Momani, K., *Atmos. Res.*, **2005**, *73*, 87-100.
- [34] Al-Fawwaz, A. T.; Al-Khazaleh, K. A., *J. Environ. Sci. Eng. A*, **2017**, *6*, 395-401.
- [35] VROM (Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer) Ministry of Housing, Spatial Planning and Environment. Circular on Target Values and Intervention Values for Soil Remediation, Netherlands., **2000**.
- [36] FAO/WHO (Food and Agriculture Organization/World Health) Codex Alimentarius Commission. Food additives and contaminants. Joint FAO/WHO Food Standards Programme, ALINORM 10/12A., **2001**.
- [37] Abdulrashid, L.; Yaro, A.; El-Ladan, Y. I., *Dutse J. Pure Appl. Sci.*, **2017**, *3* (1), 407-421.
- [38] Chen, X.; Xia, X.; Zhao, Y.; Zhang, P., *J. Hazard. Mater.*, **2010**, *181* (1-3), 640-646.
- [39] Akbar, K. F.; Hale, W. H. G.; Headley, A. D.; Athar, M., *Soil Water Res.*, **2006**, *1* (4), 158-163.
- [40] Khan, M. N.; Wasim, A. A.; Sarwar, A.; Rasheed, M. F., *Environ. Monit. Assess.*, **2011**, *182* (1-4), 587-595.
- [41] Sezgin, N.; Ozcan, H. K.; Demir, G.; Nemlioglu, S.; Bayat, C., *Environ. Int.*, **2003**, *29* (7), 979-985.
- [42] Yay, O. D.; Alagha, O.; Tuncel, G., *J. Environ. Manage.*, **2008**, *86* (4), 581-594.
- [43] Zhang, J.; Liu, C. L., *Estuar. Coast. Shelf Sci.*, **2002**, *54* (6), 1051-1070.
- [44] Taylor, S. R.; McLennan, S. M. *The Continental Crust: Its Composition and Evolution*. Blackwell Scientific Publications, Oxford: 1985.