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Contamination of Roadside Soil, Plants, and Air With Heavy Metals in Jordan, A Comparative Study

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Copper, lead, cadmium, and zinc levels were analyzed by atomic absorption spectrophotometry in surface soil, plants, and air samples taken from both sides of the major highway connecting Amman with the southern parts of Jordan. Elevated levels of the studied elements were found in both soil and plants on the east side and on the west side of the road compared with the background values. The higher levels of heavy metals east of the road were due to the westerly prevailing wind at the sampling sites. The comtamination decreased exponentially with distance from the edge of the road and dropped to the background level at about 60 m. In soil samples, the average concentrations, 1.5 m east of the highway, were 29.7, 0.75, 188.8 and 121.7 μg/g for Cu, Cd, Pb, and Zn, respectively. The levels of these elements in plants 3 m east of the highway were 31.3, 7.3, and 98.7 μg/g for Cu, Pb, and Zn, respectively, whereas for air they were 0.40, 0.94, and 0.26 μg/m^3. The values of the heavy metals suggest that automobiles are a major source of these metals in the roadside environment and also these values were compared with results found by other investigators in various countries worldwide. Finally, the roadside soil and plants had significantly high contents of heavy metals and their levels increased with increasing traffic densities and furthermore, they reached elevated levels in urban areas.

Key words: Roadside Soil, Plants, Air, Heavy metal pollution, Jordan

Introduction

Roadside soils often contain high concentrations of metallic contamination. The bioavailability and environmental mobility of the metals are dependent upon the form in which the metal is associated with the soil. Lead street dust and roadside soil has been extensively studied, and found to be present at elevated levels[1–4]. The lead in roadside soil is mainly found in the form of lead sulfate[3]. Little interest has been focused on the contamination of roadside soil by other heavy metals. Metals, such as Cu, Fe, Zn, and Cd are essential components of many alloys, wires, tires and many industrial processes, and could be released into the roadside soil and plants as a result of mechanical abrasion and normal wear. Analyses of roadside soil[3,5,6] and plants[7,8] revealed that they contain elevated levels of these heavy metals. Toxicities of some heavy metals to man and animals are well known and were published some years ago[9,10]. Of all the toxic metals in the environment, lead is by far the one of most concern; it poisons many thousands of people annually, especially children in urban areas[11].

During the last few years, the number of vehicles in Jordan, mostly operated by leaded fuel, have

increased rapidly leading to increasingly high levels of some heavy metals and other pollutants in the dust, soil and plants near highways in both rural and urban areas. Although there have been a considerable number of studies on the concentrations of heavy metals in roadside soil and plants, the vast majority have been carried out in developed countries with long histories of industrialization and extensive use of leaded gasoline since 1935[1,2,7,8,10–12]. Very few studies have been carried out in developing countries such as Jordan and data on pollutant metal concentrations and distribution in such areas are extremely scarce. Therefore, this study was initiated to assess the level of contamination of surface roadside soil, plants, and air by some heavy metals along a major traffic highway, since there have been no studies about the extent of contamination of the roadside ecosystem by priority heavy metal pollutants.

Experimental

Sampling Sites

Seven sites were selected for the study along the only highway connecting Amman, the capital, with the southern parts of the country. These sites cover the distance from Jiza (site 1), which represents a rural area, to the seventh circle in Amman city (site 7), which is considered an urban area (Figure 1). At each site, samples were collected at different distances from the edge of the main road (1.5, 10, 25, and 60 meters) on both sides, east and west. It is worth mentioning that there is a prevailing westerly wind at the sampling sites and the sites are numbered in order of increasing traffic density.

Sampling Procedure

Samples were collected from July 1995 to June 1996 to avoid rain washing out the heavy metals. Five soil samples (the upper 2 cm) were collected from each, at the above mentioned distances at each site, with a stainless steel trowel. The samples were stored in polyethylene bags then treated and analyzed separately. The plant samples (Anabasis Articulata) were collected at each indicated distance, if present, and transported to the laboratory in polyethylene bags. The plants were washed with demineralized water and the green shoots were dried at 80 °C for 24 hrs. Air samples were collected from each site, 1.5 m east of the main road, with a Hi-volume air sampler (GL 2000 H from Graseby, Ohio, USA) using Whatman-41 filters (8×10 in, pore size = 0.45 μm) and flow rate of 0.90 m^3/min. The air samples was placed with its intake nozzle about 3 m above the ground level of the highway. Five air samples were taken from each site covering the sampling period from 6 a.m. to 6 p.m, where the traffic density was expected to be heavy, especially during the morning and evening rush hours. Sample filters were kept in polyethylene bags to minimize sample loss until the time of analysis.

Sample Preparation and Analysis

Soil samples were gently ground using an acid washed porcelain pestle and mortar and then passed through a 0.2 mm nylon sieve. The sieved samples were dried at 90 °C for 24 hours. About 1 g of soil was accurately weighed and treated with 10 mL aliquots of high purity concentrated nitric acid. The mixture was heated in a test tube block-heater until dry and then cooled. This procedure was repeated with another 10 mL concentrated nitric acid followed by 10 mL of 12 M HCl. The digested soil samples were then warmed in 20 mL of 2 M HCl to redissolve the metal salts. Extracts were filtered through Whatman No. 40 filter papers, and the volume was then adjusted to 25 mL with deionized water in polyethylene volumetric flasks[4]. Metal

analysis was carried out with a flame atomic Absorption spectrophotometer (Varian-800) with background correction and a graphite furnace (Varian GTA 100). Quantitation of Pb, Cu, Zn, and Cd was carried out using standard solutions in the same acid matrix. Analysis of plant samples were carried out according to the literature[8] using flame AA. However, air particulate samples were prepared by the acid extraction method described elsewhere[12]

Reagent blanks for soil, plants, and air filters were also prepared by carrying out the whole extraction procedure, but without samples.

The accuracies of these methods were checked by analyzing NBS standard reference materials and were found to be better than 10%. Background soil and plant samples were collected 60 m west of the road, away from the effect of motor vehicle emissions, since the prevailing wind direction in the sampling sites was westerly.

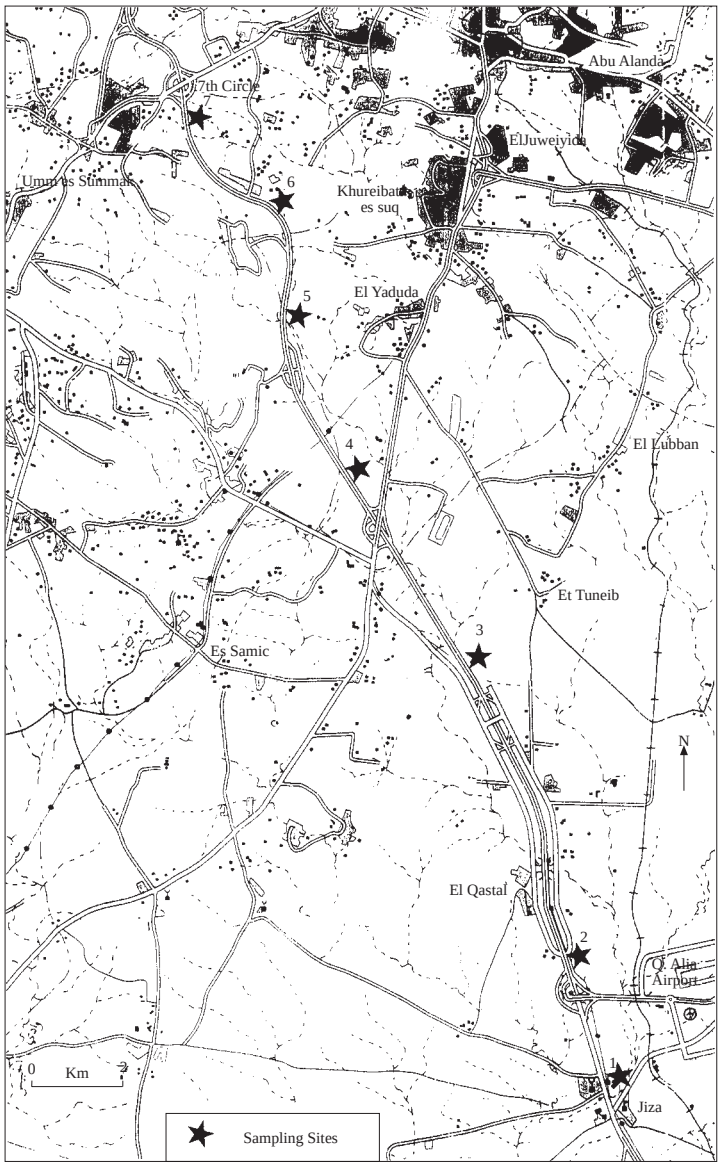

Figure 1. Location of the sampling sites.

Results and Discussion

Soil Contamination

Table 1 gives the mean and the concentration range of four heavy metals in surface soil, taken from the seven sites, at different distances from the main road. Copper concentrations 1.5 m, 10 m, 25 m, and 60 m east and 1.5 west of the edge of the road exhibited considerable contamination, since the background level (soil 60 m west) is 15.5 μg/g. Cu is derived from engine wear, from thrust bearings, bushing and bearing metals. Some studies show much higher contaminaton levels[4,13], but our result is higher than those found in North Wales[14] and Auckland[16] (Table 2).

Table 1. The arithmetic mean, standard deviation and concentration range of Cu, Cd, Pb and Zn in roadside soil (μg/g).

Distance (m)	**Cu mean±sd Range**	**Cd mean±sd Range**	**Pb mean±sd range**	**Zn mean±sd range**
1.5 m E⋆	29.7±7.2	0.75±0.32	188.8±71.2	121.7±13.8
	22.6-44.6	0.38-1.15	89.6-272.2	94.0-140.8
10 m E	19.8±8.5	0.43±0.17	13.7±7.2	57.1±7.9
	14.5-23.2	0.23-0.57	8.8-28.8	45.0-81.1
25 m E	19.6±4.2	0.32±0.13	9.9±2.9	49.0±6.8
	14.9-22.0	0.25-0.38	7.3-12.4	38.6-58.6
60 m E	17.9±5.7	0.33±0.12	6.9±4.5	48.1±11.2
	14.0-19.9	0.22-0.36	3.7-11.6	41.0-69.7
1.5 m W⋆	22.5±10.3	0.55±0.23	61.5±5.6	75.0±17.2
	18.7-25.5	0.32-0.79	51.1-69.5	52.1-95.5
10 m W	16.6±6.8	0.29±0.09	8.1±2.8	48.7±6.8
	14.0-17.9	0.22-0.35	6.5-10.2	42.1-52.7
25 m W	16.1±3.7	0.28±0.11	6.5±1.1	46.3±5.7
	13.9-18.1	0.23-0.32	5.2-7.2	40.2-53.1
60 m W	15.5±2.9	0.28±0.08	6.3±0.9	41.6±12.3
	14.0-16.2	0.21-0.32	5.7-7.1	36.5-48.9

⋆E: East of the roadside; W: West of the roadside.

Cadmium, on the other hand, exhibited lower levels of contamination than those of other studies[3,14,17]. However, the level of Cd in this study is comparable with those found in Birmingham[28] and about twice that in Ecuador[6]. The sources of cadmium in the urban areas are much less well defined than those of Pb, but metal plating and tire rubber were considered the likely sources of Cd[15]. Cadmium and Zinc are found in lubricating oils as part of many additives. It was reported that the cadmium level in car tires is in the range of 20 to 90 μg/g as associated Cd contamination in the process of vulcanization[16]. In the absence of any major industry in the sampling sites, the levels of Cd could be due to lubricating oils and/or old tires, that are frequently used, and the rough surfaces of the roads which increase the wearing of tires.

Table 2. The levels of Cu, Cd, Pb and Zn (μg/g) in roadside soil compared with other studies worldwide.

Place	Cu	Cd	Pb	Zn	Ref
Amman	29.7	0.75	188.8	121.7	This study
Lancaster	19-199	5.2	-	300-530	3
Hong Kong	120	1.1	991	633	4
Ecuador	-	0.36	293	509	6
Nigeria	61	1.3	247	163	13
North Wales	24	6.8	1779	1143	14
Auckland	27	0.4	1650	180	16
London	-	4.2	1354	513	17
Birmingham	-	0.70	180	205	18
USA (different cities)	-	0.89	444	-	28

Lead, the element of most concern in environmental heavy metal pollution, exhibited high levels of contamination as we got closer to the highway. Decreases elemental concentrations with distance from the highway would indicate surface soil contamination by extraneous sources. Whereas unchanging levels would show that the heavy metal concentrations were a function of the soil itself. Since the fuel used by automobiles in Jordan is mostly leaded, the most probable source of such contamination is the lead particulate matter emitted from gasoline vehicles which settles not far from the highway[19]. As the distance from the road increased, the Pb level fell sharply reaching the normal soil lead level, which was estimated to be less than 7 μg/g. Therefore, the lead contamination of soil was restricted to short distances from both sides of the highway. However, some investigators found that lead contamination of soil may reach 100 m from the main road[16]. The average value of lead 1.5 m east the road was much lower than those found in Hong Kong[4], North Wales[14], Auckland[16], and London[17], and it is comparable with that found in Birmingham[18] as shown in Table 2.

Zinc, in the soil next to the highway, exhibited elevated levels, 121.7 μg/g 1.5 m east of the road. This value is small compared with many other studies[3,4,6,14,17]. In this study, the Pb/Zn ratio in soil was greater than unity, which may indicate soil-lead pollution caused by automobiles. Similar results were found by other investigators[4,13,14,17]. However, other reports[6,18] found a ratio of less than unity, which was related to the local conditions. Since no major industry exists in the study areas such as smelting operations, we may assume that the primary sources of Zn are probably the attrition of motor vehicle tire rubber exacerbated by poor road surfaces, and the lubricating oils in which Zn is found as part of many additives such as zinc dithiophosphates.

Figure 2 illustrates the distance profile of the four elements determined in the roadside soil. The figure shows two main trends; firstly, the metal contamination decreased with distance from the highway, and this is consistent with what was found in Nigeria[13], and secondly, the clearly higher levels of the elements east compared with those west of the road. This latter trend can be attributed to the westerly prevailing winds in the study areas. Lead concentration exhibited a very sharp decrease when going from 1.5 m to 10 m east of the road compared with the other elements in the same region, which may be directly related to the high level of automobile emissions. When the concentrations of heavy metals 1.5 m from the edge of the road are compared with those 60 m west (background levels), it is clear that there is a higher variation in lead levels compared with those of Cd, Cu, and Zn. This could be explained by the relatively high background values of Cd, Cu and Zn in the samples.

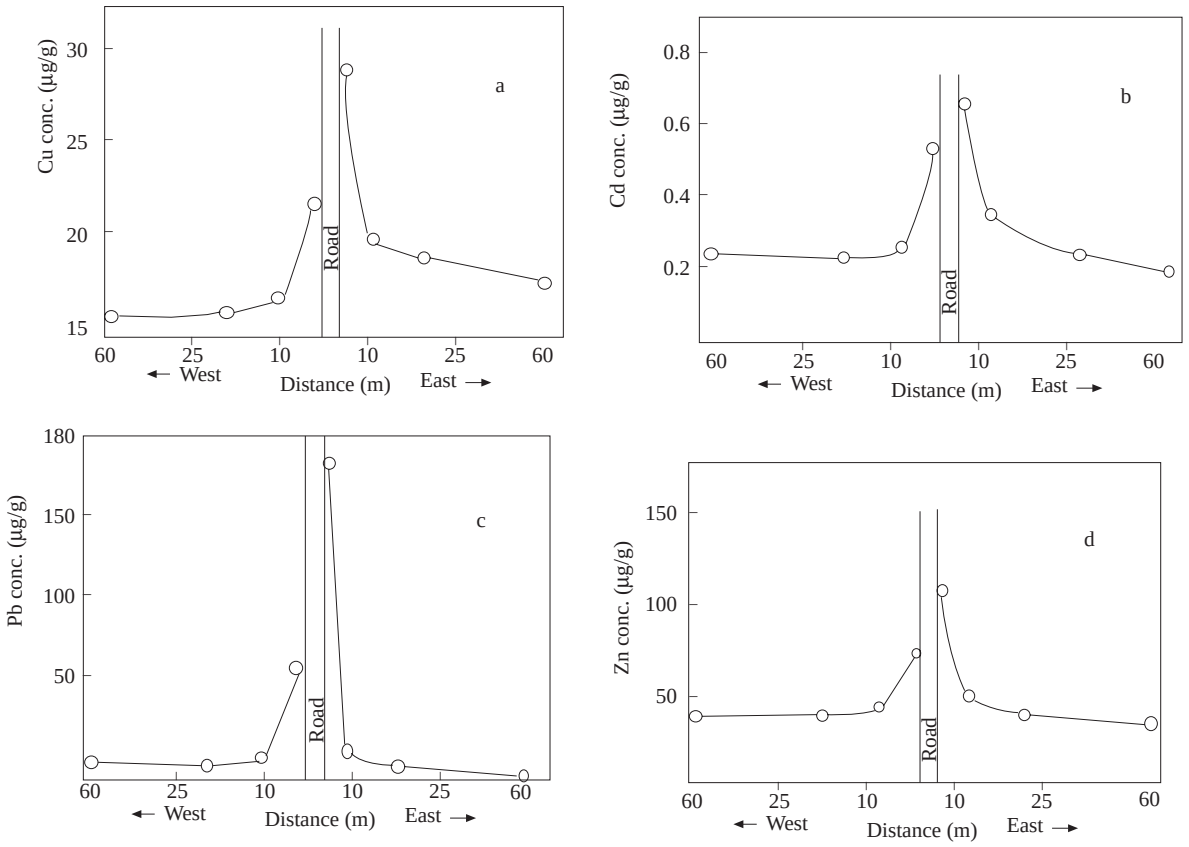

Figure 2. Heavy metal contents of soil as a function of distance from the highway, (a) Cu; (b) Cd; (c) Pb; and (d) Zn.

Table 3. The average concentrations of Cu, Cd, Pb and Zn in roadside soil (μg/g) at various sampling sites (1.5 m east of the highway).

Site#	Vehicles/hr	Cu±sd	Cd±sd	Pb±sd	Zn±sd
1	1000	27.3±6.2	0.56±0.08	89.6±19.2	121.1±17.5
2	1100	30.7±7.6	0.94±0.21	129.0±23.5	140.8±18.5
3	700	44.6±9.9	1.14±0.25	126.8±45.3	132.7±33.5
4	1300	22.6±3.2	0.55±0.15	236.2±46.0	115.5±12.5
5	1500	24.9±4.5	0.54±0.11	233.0±56.9	119.7±19.8
6	1600	28.4±3.4	0.38±0.09	233.5±65.8	94.0±8.8
7	2200	29.1±9.7	1.15±0.18	272.2±80.1	128.2±13.9
Average	1343	29.7±7.2	0.75±0.32	188.8±71.2	121.7±13.8

Correlational calculations, performed on the concentrations of the heavy metals in surface soil, showed that significant correlations (p=0.05) are present between the four studied elements (Figure 3). This indicates that roadside soil contamination by metals originated from a common anthropogenic source, with probably automobiles as a major common source.

Table 3 illustrates the average concentration of the heavy metals of interest with site number. The table shows a general increase in concentrations with number of motor vehicles at each site. Statistical analysis, performed with Statistical Package for Social Sciences (SPSS), showed a good correlation between

Cd and Cu values (r=0.68, p=0.08), Cd and Zn (r=0.79, p=0.03) and Pb with number of automobiles per hour (r=0.85, p=0.01). As the sampling areas have no industry, we may assume that the heavy metals analyzed derive mostly from car traffic on the main motorway from Jiza (site 1) to the 7th circle (Site 7). Sites 1, 2 and 3 exhibited higher levels of heavy metals compared with other sites (4 and 5) but less than the last two sites (6 and 7). This is probobly due to high percentage of heavy trucks passing through sites 1, 2 and 3 but not through the other sites.

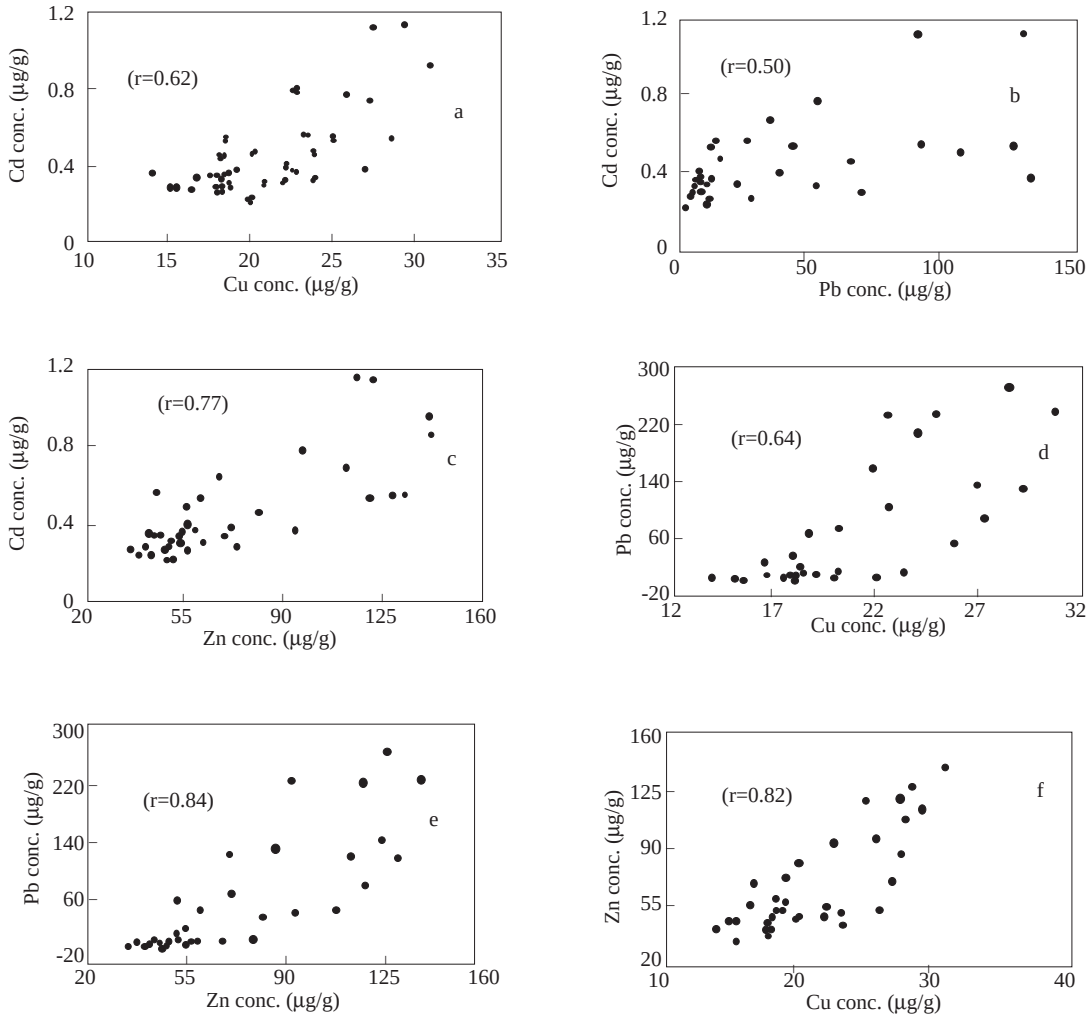

Figure 3. Relationships between the concentrations of heavy metals in soil, (a) Cd vs Cu; (b) Cd vs Pb; (c) Cd vs Zn; (d) Pb vs Cu; (e) Pb vs Zn; and (f) Zn vs Cu.

Plant Contamination

Cadmium levels in plants were below the detection limits of the flame AA used in this study. Other studies have had similar results[4,21]. Therefore, the study of plants contamination was restricted to Cu, Pb, and Zn. Table 4 shows the concentration of the three elements in the studied plant (Anabasis Articulata). However, Table 5 summarizes a comparison between our results and some other studies worldwide. The selectivity of different plants for heavy metals is different, but rough comparison of heavy metals in plants with other

studies shows that the copper level was higher than those found elsewhere[8,16]. However, the lead level in this study, was much lower than that of others[4,16]. This could be due to different plant types and different number of vehicles per day in those places. High correlation coefficients have been found between the different heavy metals in plants: r=0.92, 0.86, 0.94 between Cu and Pb, Cu and Zn, and Pb and Zn, respectively. These high values of r may indicate common sources of heavy metals.

All values of zinc in plants exhibited similar trends to those found in surface soils. Correlational calculations between heavy metals in soil and plants gave high correlation coefficients: r=0.74, 0.89, and 0.92 for Cu, Pb, and Zn, respectively. This may indicate that significant heavy metal pollution from an extraneous source is taking place. Figure 4 shows an exponential decrease in the levels of zinc and other elements with increasing distance from either side of to road. The zinc levels are comparable with those of many investigators worldwide, as Table 5 shows.

Table 4. The average concentrations of Cu, Pb, and Zn (μg/g) in roadside plants at different distances from the highway).

Distance, m	Cu±sd	Pb±sd	Zn±sd
3 m E⋆	31.3±18.2	7.3±3.1	98.7±40.0
10 m E	30.4±8.9	4.2±2.6	52.9±18.3
25 m E	28.5±5.6	4.0±1.6	49.0±17.1
50 m E	26.5±4.5	3.9±1.8	46.9±13.2
3 m W⋆	30.6±6.3	5.1±0.9	90.5±22.4
10 m W	10.4±2.7	2.7±0.4	33.8±9.9
25 m W	10.3±3.6	1.7±0.4	21.1±4.4
50 m W	10.0±1.8	1.1±0.2	14.9±2.9

⋆E: east of the roadside; W: west of the roadside.

Table 5. The levels of Cu, Pb, and Zn (μg/g) in plants compared with other studies worldwide.

Place	Cu	Pb	Zn	Ref
Amman	31.4	7.3	98.7	This study
Hong Kong	17	134	124	4
Dutch Coast	3-24	-	30-180	8
Auckland	17	180	-	16
USA	-	-	32-85	21
Belgium	-	-	37-114	29

Air Contamination

Copper, lead and zinc concentratios were determined in the air filters with flame AA. The cadmium concentrations were undetected by this technique. This was also found by other investigators[23,24]. Table 6 represents the average concentrations of Cu, Pb, and Zn at the sampling sites. The table shows that the average copper concentration varied from 0.26 to 0.60 μg/m^3. These values are lower than those determined in Riyadh[25] but higher than those found in Taiwan[23], in Cairo[24], in Chile[27] and in Spain[31].

Lead, on the other hand, exhibited lower compared with those found in Riyadh[25] and in Cairo[26], but higher than those determined in Taiwan[23], the Black Sea[31] and comparable with those in Spain[31]. Zinc levels ranged from 0.12 to 0.38 μg/m^3. These values are comparable with those found in Riyadh[25] and

in Chile[27] but lower than those in Taiwan[23]. Table 7 represents a comparison of our results with those of other investigators worldwide.

Figure 5 illustrates the relationshis between metal concentrations and the average number of vehicles per hour that passed during the sampling period at various sampling sites. The figure shows that the levels of the three elements (Cu, Pb, and Zn) increased one way or another, with increasing numbers of vehicles. This may indicate that automobiles are a major source of these elements in the urban atmosphere.

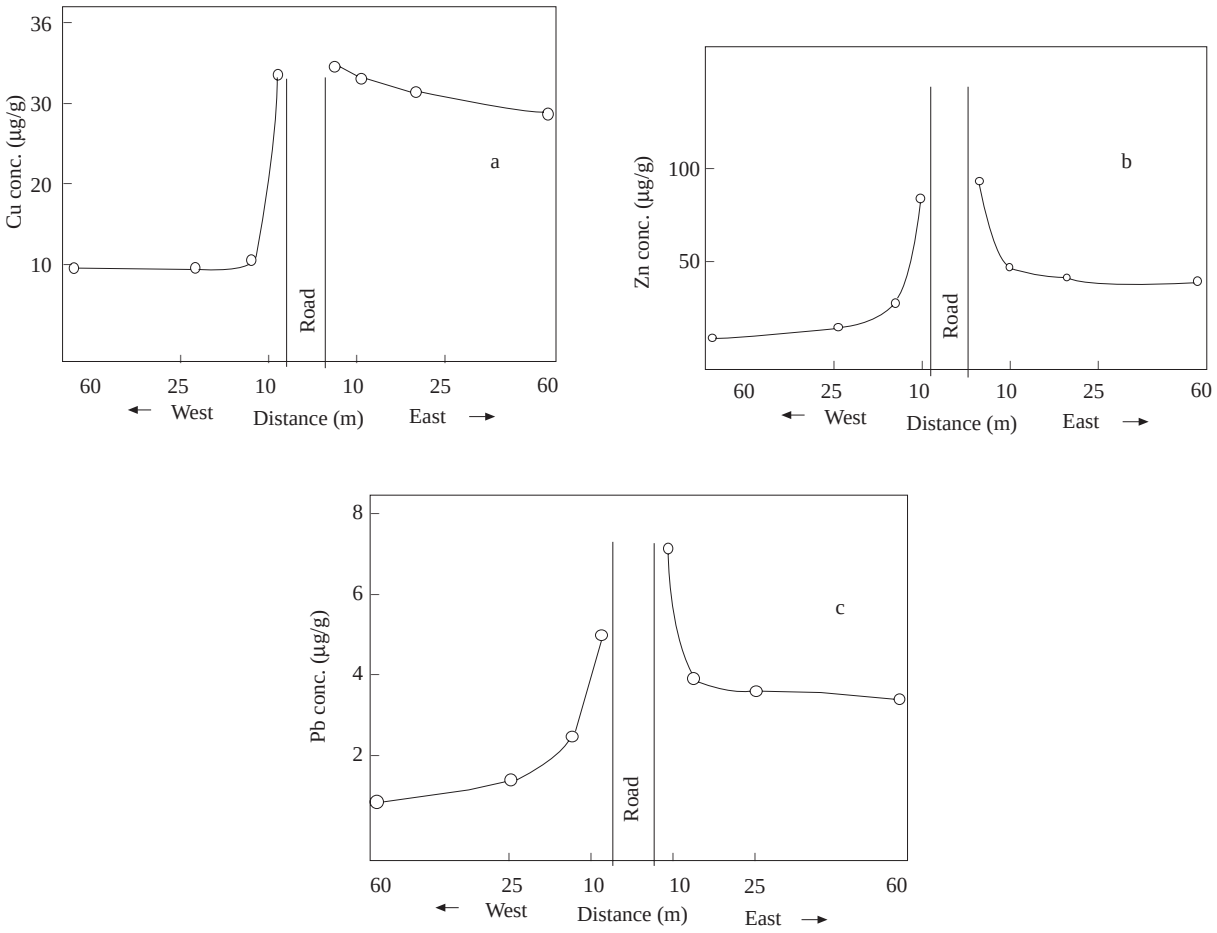

Figure 4. Heavy metal contents of plants as a function of distance from the main highway, (a) Cu; (b) Zn; and (c) Pb.

Table 6. The average concentrations of Zn, Cu and Pb in roadside air ($\mu g/m^3$).

Site#	Zn	Cu	Pb	Vehicles/hr
1	0.17±0.05	0.31±0.07	0.61±0.15	1000
2	0.25±0.06	0.48±0.11	0.64±0.11	1100
3	0.12±0.04	0.26±0.06	0.26±0.08	700
4	0.26±0.08	0.31±0.13	0.99±0.35	1300
5	0.32±0.07	0.43±0.12	1.37±0.25	1500
6	0.30±0.09	0.38±0.06	1.09±0.22	1600
7	0.38±0.13	0.60±0.14	1.63±0.32	2200
Average	0.26±0.09	0.40±0.12	0.94±0.47	1343

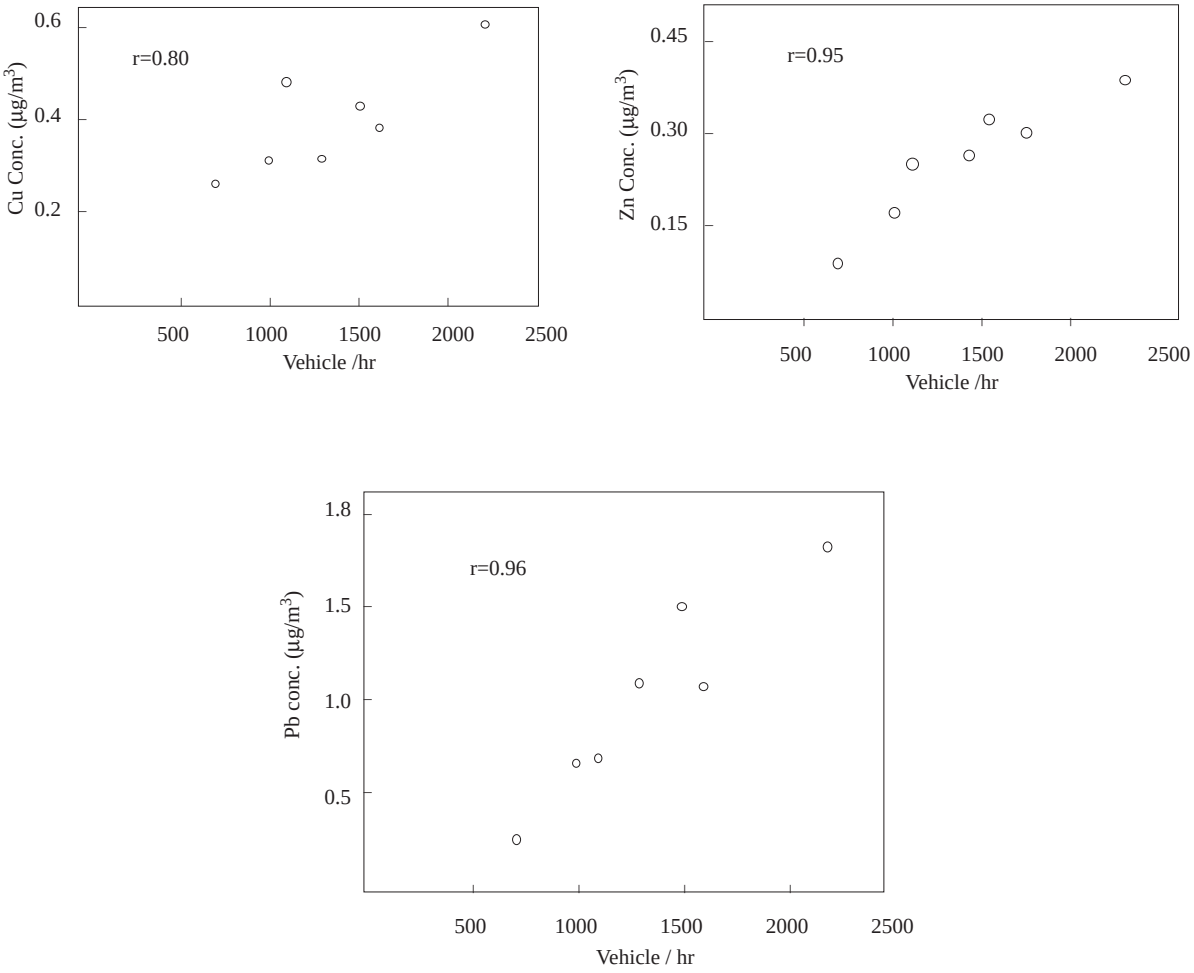

Figure 5. Relationships between the concentrations of heavy metals in air and the average number of vehicles per hour at the various sampling sites, (a) Cu; (b) Zn; and (c) Pb.

Statistical analysis of the data in Table 6, shows significant differences (p=0.05) between Zn and Cu (r=0.82), Zn and Pb(r=0.96), and Cu with Pb (r=0.73) at the different sampling areas. Also, the correlation coefficients between Zn, Cu and Pb with number of vehicles per hour (r=0.95, 0.80, and 0.96 respectively) suggest that these heavy metals come from the same source, namely automobile emissions.

Table 7. The levels of Cu, Pb, and Zn ($\mu g/m^3$) in air compared with other studies worldwide.

Place	Cu	Pb	Zn	Ref
Amman	0.26-0.60	0.26-1.63	0.12-0.38	**This study**
Taiwan	0.17	0.78	1.56	23
Cairo	0.19	0.01	0.09	24
Riyadh	0.24-2.91	0.20-4.09	0.04-0.62	25
Cairo	-	0.6-3.0	-	26
Chile	0.02-0.22	-	0.02-0.26	27
Black sea	-	0.051	-	30
Spain	0.013-0.0082	1.55-0.70	0.047-0.022	31

Conclusions

From the previous discussion, the following conclusions may be drawn:

1- The roadside surface soil, plants, and air in Jordan are relatively contaminated with heavy metals when compared with the background values.The comtamination is relatively lower than that of other places worldwide.

2-More heavy metal contaminations in soil and plants was observed on the east side of the road than the west side. This could be due to the westerly prevailing winds.

3- The levels of heavy metal contamination in both surface soils and vegetation, exponentially decreased to background levels with distance on either side of the highway. The decrease of elemental concentrations with distance from the highway would indicate aerial deposition of metal particulates in the roadside environment from extraneous sources and not a function of soil type. In Jordan motor vehicles that burn leaded gasoline are mostly responsible for the build up of heavy metals in soild and in grasses along the highway through the emissions of particulates.

4- The concentration of Pb, especially in soil, exhibited a larger variation with distance from the road than those of Cd, Cu and Zn. This may be explained by the relatively higher background values of Cd, Cu and Zn in the samples.

5- The roadside environment had a significantly high content of heavy metals, especially Pb, and generally their levels increased with increasing traffic volumes and become elevated in urban areas.

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