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Assessment of Heavy Metal Contamination in Roadside Surface Soil and Vegetation from the West Bank

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Abstract. Concentrations of heavy metals (Pb, Cd, Cu, Zn, Fe, Mn, Ni, and Cr) were investigated in roadside surface soil and the common perennial herb inula (*Inula viscosa* L., Compositae). Samples were collected at different distances (0–200 m) perpendicular to a main road that connects two main cities in the West Bank. Average concentrations of metals in soil samples were: Pb, 87.4; Cd, 0.27; Cu, 60.4; Zn, 82.2; Fe, 15,700; Mn, 224; Ni, 18.9; and Cr, 42.4 $\mu g \cdot g^{-1}$. In plant leaves, concentrations were: Pb, 7.25; Cd, 0.10; Cu, 10.6; Zn, 47.6; Fe, 730; Mn, 140; Ni, 4.87; and Cr, 7.03 $\mu g \cdot g^{-1}$. Roadside contamination was obvious by the significant negative correlations between concentrations of metals in soil and plant samples and distance from road edge. Only cadmium concentrations in soil and plant samples were not associated with roadside pollution. Roadside contamination in plants and soil did not extend much beyond a 20 m distance from road. *I. viscosa* reflected roadside contamination better than soil and their metal concentrations showed much less fluctuations than those in soil samples. Washing plant leaves decreased Pb and Fe concentrations significantly, indicating a significant aerial deposition of both. *I. viscosa* can be considered as a good biomonitor for roadside metal pollution.

Motor vehicles introduce a number of polutants into the environment. Roadsides receive considerable amounts of these traffic-generated pollutants, particularily lead (Sutherland and Tack 2000). Therefore, many studies and surveys have been conducted in order to assess heavy metal contamination in roadside and urban soils and plants (Ho and Tai 1988; Fatoki 1996; Garcia and Millán 1998; Sánchez-Martin *et al.* 2000). Some studies concentrated on evaluating metals in cultivated soils (Frank *et al.* 1976; De Boo 1990; Crisanto-Herrero and Lorenzo-Martin 1993); others focused on urban and suburban soils, where most people live (Carey *et al.* 1980; Mielke 1994; Sanchez-Martin *et al.* 2000). Recent studies concentrated on evaluating lead levels in different grain size fractions of road-deposited sediments (Sutherland 2003) or on levels of total and partially extractable metals in roadside soils (Sutherland and Tolosa 2001). These studies confirmed the presence of elevated concentrations of different metals, especially Pb, Zn, and Cu. From a human health perspective, high concentrations of these metals are of great concern due to their potential toxicity and biomagnification (Ragan and Mast 1990).

In the West Bank, environmental assessment and monitoring are almost absent. The political situation of this region was responsible for the long years of environmental negligence and deterioration. According to MEnA (1999), about 90% of the wastewater generated in the Palestinian Territories is discharged without any treatment into the environment, commonly in wadis, agricultural drainage channels, open fields, or roadsides. In addition, collection services for solid wastes in the West Bank cover about 67% of the population. Uncontrolled dumping of the remaining wastes on vacant lands and roadsides is quite common. Moreover, solid wastes are burned at open dumping sites, leading to severe atmospheric pollution. Wrecked cars, scrap metals, construction, and industrial and medical wastes are often seen along main roads outside city borders (Al-Humaidi 1994). The main sources of atmospheric pollution in the West Bank are industrial air emissions, dense traffic and old cars, dust and particulate matter from stone quarries, and solid waste burning in open dumping sites. Transportation alone contributes about 40–50% to air pollution in the West Bank (MEnA 1999).

Therefore, this study is thought as a pioneer one to investigate heavy metal contamination in roadside soils and vegetation from the West Bank. For this purpose, the main highway (Nablus–Ramallah) that connects the northern West Bank with the middle and southern parts was chosen (Figure 1). This highway is about 65 km. On both sides of the highway, agricultural lands exist and livestock are often seen grazing. Inula (*Inula viscosa* L., Compositae), the most common perennial herb along Palestinian roads, was selected for this study. The abundance of this plant along roads indicates tolerance to possible roadside contamination and makes it a suitable bioindicator plant for further and future monitoring programs. The eight metals investigated were Cd, Pb, Cu, Zn, Ni, Fe, Cr, and Mn.

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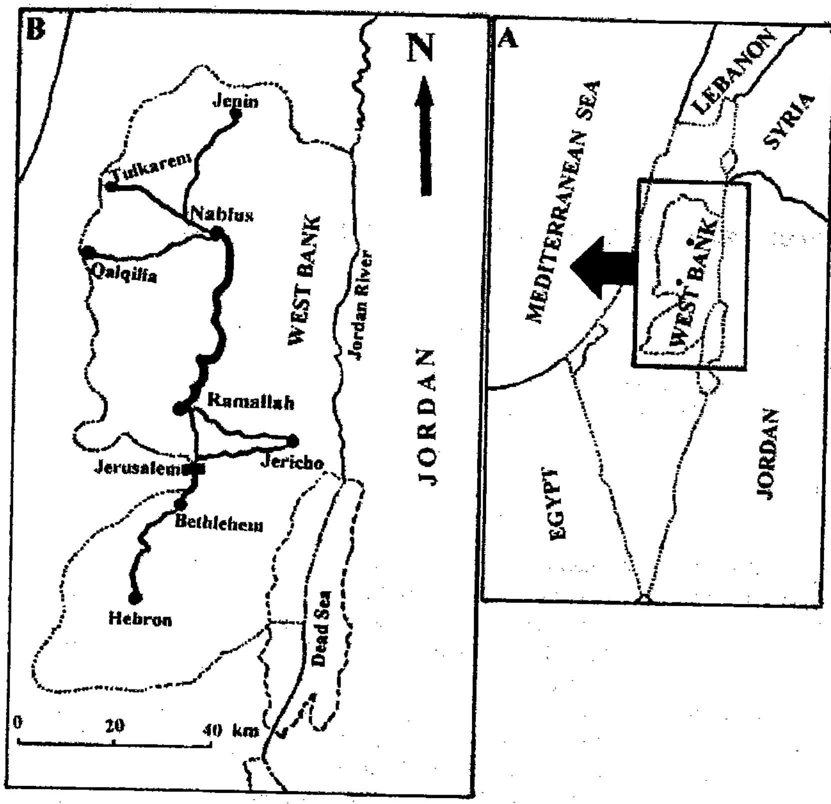

Fig. 1. (A) The geographical location of the West Bank. (B) Main roads in the West Bank including Nablus–Ramallah Road

Materials and Methods

The Study Area

The highway passes through agricultural lands that are surrounded by mountains from both sides. The region has a typical Medditerranean-type climate, that is characterized by a short winter (November to February) and a long period of drought.

The soil type that dominates these lands is the red soil called terra rosa. This soil is characterized by a pH value of 8–9, an organic matter content of 1.41–2.46%, and a carbonate content (as CO_2) of 10–70% (near road edge), and its CEC is about 64–72 meq/100 g.

The traffic volume on this highway is about 5000 automobiles/h, half of which are cars or trucks that use diesel and two-thirds of the remaining half are old cars that still use leaded fuel.

Sampling and Preparation of Samples

Surface soil samples (0–5 cm) were collected in triplicate (from different sites) at different distances perpendicular to the Nablus–Ramallah highway in November 2000. Distances of sampling from road edge were 0, 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 20, 25, 30, and 200 m. Samples were collected in clean plastic bags using a plastic spoon and transferred back to the laboratory, where samples were oven-dried, crushed, sieved through a 1-mm sieve, and stored in clean glass vials.

Plant leaves were collected in triplicates at the same distances as above. Leaves from two or three plants were pooled together in each sample, kept in plastic bags, and transferred back to the laboratory. Plant leaves were washed thoroughly with deionized double-distilled water to remove adsorbed dust and metals. Then samples were oven-dried at 60°C until a constant weight. Finally, leaves were ground to fine powder using a grinder with a stainless-steel knife and stored in clean glass vials.

Analytical Procedures

Subsamples (about 0.2 g soil and 0.5 g plant powder) were digested in a sand bath using a mixture of 1:1 nitric:perchloric acids (Suprapur, Merck). The volume of the mixture used was 10 times the sample's weight. Temperature of the sand bath was gradually increased up to 200°C over the first 2 h. Thereafter, digestion continued over another 6 h until no more fumes were liberated and the color of the mixture turned pale-yellow to colorless (Swaileh and Adelung 1994). After-that, samples were filtered through Whatman No. 1 filter papers and volumes were adjusted to 25 ml using distilled water. Blanks and reference materials (lake sediment, IAEA-SL-1, and hay powder, IAEA/V-10) were run with the samples. Finally, concentrations of the eight metals were measured by inductively coupled plasma spectrophotometry (ICP Optima 3000; Perkin–Elmer, USA). All accepted recoveries were within the confidence limits of the certified values (Table 1).

Statistical Analysis

Statistical analysis of data was done using SYSTAT 5.02 for Windows software (Wilkinson 1992). Statistical differences were tested using analysis of variance (ANOVA) and *t*-test. Statistical significance of regressions was verified using the same software.

Table 1. Concentrations of heavy metals in the reference material (lake sediment SL-1 and hay powder IAEA/V-10) provided by the International Atomic Energy Agency, Vienna, Austria

	Concentration ($\mu g \cdot g^{-1}$) (confidence interval; $\alpha = 0.05$)	
Metal	Lake sediment	Plant (hay)
Cd	0.26 (0.21–0.31)	0.03 (0.02–0.05)
Cr	104 (95–113)	6.5 (5.6–7.1)
Cu	30 (24.4–35.6)	9.4 (8.8–9.7)
Fe	67.4[a] (65.7–69.1)	0.185[a] (0.177–0.190)
Mn	3.46[a] (3.3–3.62)	47 (32–52)
Ni	44.9 (36.9–52.9)	4 (3.8–4.9)
Pb	37.7 (30.4–45.1)	1.6 (0.8–1.9)
Zn	223 (213–233)	24 (21–27)

[a] Concentrations in $mg \cdot g^{-1}$.

Results

Metals in Soil and Plant Samples

A total of 45 soil samples and 57 plant samples were collected and analyzed in the present study. A statistical summary of the concentrations of metals in these samples is shown in Table 2. According to their concentrations in soil samples, metals can be ordered as Fe > Mn > Pb > Zn > Cu > Cr > Ni > Cd. In the plant samples, metals had the following order: Fe > Mn > Zn > Cu > Pb > Cr > Ni > Cd. With the exception for Pb, metals in soil and plant samples were found to follow a similar order. However, concentrations of all metals in soil were higher than those in plants.

Concentration–Distance Relationship

Statistically significant relationships existed between concentrations of Pb, Cu, and Zn in soils and distance of sampling from road edge (Table 3). Concentrations of Pb, Cu, and Zn in soil were found to decrease with increasing distance of sampling from road. The remaining metals (Cd, Ni, Mn, Fe, and Cr) were found to be independent of distance from road (Figure 2). Concentration of Pb in road edge soil (0 distance) was found to be 422 $\mu g \cdot g^{-1}$. This value decreased sharply to about 200 $\mu g \cdot g^{-1}$ in soil collected at a 1-m distance. Concentration of Pb in soil samples collected at 9 m (16 $\mu g \cdot g^{-1}$) decreased slightly with increasing distance of sampling until it reached 10 $\mu g \cdot g^{-1}$ in samples collected at a 200-m distance. The decrease in Cu concentration with increasing distance from road edge was similar to that of lead, but concentrations decreased slightly beyond a 5-m distance from road edge. No sharp decrease in Zn concentration was observed and the decrease was gradual and fluctuating.

Concentrations of metals in plant samples collected at different distances from road edge are shown in Figure 3. All metals in plant leaves, except Cd, exhibited statistically significant negative relationships with distance from road edge (Table 3). Lead, the most important roadside pollutant, exhibited a gradual decrease from a 0- to a 15-m distance. Thereafter, no further significant decrease was observed. In contrast to soil, no sharp decrease in the concentration of any metal in plants was observed. In addition, concentrations of metals in the plant exhibited less fluctuation than in soil.

Concentration–Leaf Age Relationship

Old, fully grown leaves of *I. viscosa* were found to have significantly more Pb (about 3 times) and Fe (about 6 times) than new leaves, whereas no such difference between old and new leaves was observed for any of the remaining metals (Table 4). In addition, washing plant leaves, sampled at a 10-m distance from road edge, with distilled water was found to remove 33% of Pb and about 50% of Fe. Washing leaves did not affect the concentration of the remaining metals significantly (Table 4).

Soil–Plant Metal Correlation

Statistically significant correlations ($p < 0.0001$) existed between the concentration of some metals (Pb, Cu, Zn) in soil and plant samples. Correlation coefficients were 0.75, 0.66, and 0.64 for Pb, Cu, and Zn, respectively. Other metals did not exhibit any significant correlation.

Discussion

Concentrations of metals (Cu, Cd, Pb, and Zn) in roadside soil samples from the present study are either below (Cd) or within the phytotoxic range and the Dutch critical values set by the Dutch authorities for soils that require further investigation for possible rehabilitation or restriction of land use (Table 5). However, average metal concentrations in roadside soils are clearly higher than those found in background soil samples that were obtained from a forest in the region that is away from sources of pollution (Swaileh *et al.* 2001). Compared to results of other studies regarding metals in roadside soil (Table 5), those of the present one seem to be comparable, although Cd concentrations are less than those reported by most of these studies. With regard to Pb, the main roadside pollutant, concentrations found in this study are much less than those reported by other studies.

Average metal concentrations in *I. viscosa* leaves were clearly below the range of metal concentrations in plant leaves that are considered phytotoxic (Table 6). However, concentrations of Pb, Cu, and Zn in roadside samples of *I. viscosa* leaves were higher than those reported in leaves of the same plant from the control site (Swaileh *et al.* 2001). The ability of different plant species to accumulate metals and reflect environmental contamination has been investigated by a number of researchers (Table 6). Results of most of these studies are either comparable to (Cu and Zn) or higher than (Pb and Cd) those of the present study.

Although 24% of soil samples had high metal concentrations that require further investigations, metals in plant tissues were within normal limits. This could be related to the generally alkaline soil of Palestine, where the pH in Jordan Valley, for

Table 2. Statistical summary of the concentrations of metals ($\mu g \cdot g^{-1}$) in roadside surface soil and plant (*Inula viscosa*) samples collected along Nablus–Ramallah Road in the West Bank (number of plant and soil samples is 45 each)

	Mean		SE		Median		Minimum		Maximum	
	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant	Soil	Plant
Cd	0.27	0.1	0.02	0.004	0.25	0.09	0.09	0.05	0.59	0.17
Pb	87.4	7.25	17.2	0.816	18.7	5.90	2.22	0.21	539	18.0
Cu	60.4	10.6	11.7	0.694	17.5	10.1	4.37	4.30	321	22.7
Zn	82.2	47.6	9.47	3.693	60.5	39.9	6.18	14.3	295	110
Fe[a]	15.7	0.73	1.55	0.047	14.1	0.67	3.12	0.25	36.8	1.64
Mn	224	140	26.1	5.697	166	140	57.0	54.4	789	232
Cr	42.4	7.03	3.40	0.480	38.0	7.00	11.7	2.00	87.9	16.8
Ni	18.9	4.87	1.76	0.291	16.2	4.44	5.4	2.21	51.9	9.77

[a] $mg \cdot g^{-1}$

Table 3. Correlation coefficients between distance of sampling from road edge and metal concentration in surface soil and plant (*Inula viscosa*) samples collected along Nablus–Ramallah Road in the West Bank

	Correlation coefficient (r^2)	
	Soils	Plants
Cd	0.029	0.020
Pb	0.823*	0.557*
Cu	0.739*	0.467*
Zn	0.632*	0.539*
Fe	0.000	0.719*
Mn	0.013	0.269*
Cr	0.002	0.639*
Ni	0.086	0.484*

* $p < 0.001$.

example, reaches a maximum of 9.6 (Hadad and Mezied 1993). This high pH value makes metals unavailable to plants and, thus, reduces risks of phytotoxicity.

The dependence of the concentration of some metals in soils and plants, especially Pb, on distance from road is well known and considered as indication of traffic-related pollution (Onyari *et al.* 1991; Munch 1993; Fatoki 1996; Chronopoulos *et al.* 1997; Olajire and Ayodele 1997; Othman *et al.* 1997; Sánchez-Martin *et al.* 2000). Traffic-related metals originate mainly from combustion of leaded fuel (*e.g.*, Pb), lubricating motor oil, vehicle tire wear, and brake pads (*e.g.*, Cd, Mn, Zn, Cu) (Sadiq *et al.* 1989; Chronopoulos *et al.* 1997; Olajire and Ayodele 1997). In the present study, concentrations of Pb, Cu, Zn, and Fe in soils were found to have statistically significant relationships with distance from road (Table 3). The decrease in the concentration of Pb, Cu, and Zn with increasing distance of soil sampling seems to be related to traffic pollution. The results indicated that concentrations of Cd, Mn, Cr, Fe, and Ni in roadside soil samples are not related to traffic pollution (Figure 2). These results are in full agreement with those found by Sutherland *et al.* (2000). However, Pb exhibited the strongest correlation with distance from road (Table 3), indicating the importance of its anthropogenic enrichment from traffic pollution. A sharp decrease in the concentration of some metals in soil samples as we move from a 0- to a 1-m distance from road edge could be due to street runoff of rain water to roadside surface sediments (Bourcier and Hindin 1979; Revitt and Ellis 1980). Results of the present study indicate that roadside pollution in the West Bank does not extend far beyond a distance of 20 m from road edge (Figure 2; Pb, Cu, and Zn). Othman *et al.* (1997) observed longer distances of lead pollution along roads of Damascus city. They recommended that vegetables should be planted at least 200 m away from roadside. According to the same reference, most particulates carrying lead compounds emitted from vehicles are deposited on roadside soils (0–5 m) but some can be carried a longer distance by wind. The highest concentrations of Pb are usually observed in surface soils (0–5 cm), while below a 10-cm depth, concentrations are close to background ones (Adriano 1986; Chronopoulos *et al.* 1997).

The dependence of metal concentration in plant leaves was obvious for all metals except Cd. Moreover, concentrations of metals in plant samples were less fluctuating compared to those in soil samples. This is clear by the relatively small standard error bars. Therefore, using plants to identify roadside pollution seems to be better than soil. In addition, plants reflect the amounts of metals that are biologically available to plants. This is of great importance especially in Palestine and other regions where soil is alkaline. In addition, metals in soils depend on many factors like organic matter, carbonate, and clay contents of soil (Sánchez-Camazano *et al.* 1998). Contamination of roadside *I. viscosa* leaves with Pb extends to about 20 m from road edge. Beyond this distance, no further decrease in Pb concentration was observed. The lack of any relationship between Cd concentration in soil and distance from road is confirmed by *I. viscosa.*

Chronopoulos *et al.* (1997) studied the reduction of Pb concentrations from the periphery to the interior (60 m) of some parks in Athens, Greece. Pb contamination was found to extend to about 40 m, beyond which little change in Pb concentration was observed in leaves of *N. oleander* and *Pittosporum sinensis.* Othman *et al.* (1997) found that vegetable roadside contamination with Pb extends beyond a 80-m distance and concluded that vegetables should be planted at least 200 m from roads.

New leaves of *I. viscosa* were found to differ statistically from old (fully grown) leaves in Pb and Fe concentrations. Therefore, leaves of similar size (age) must be taken in monitoring studies in order to reduce errors when comparing samples of a plant from different sites.

Washing leaves of *I. viscosa,* collected at 10 m from road

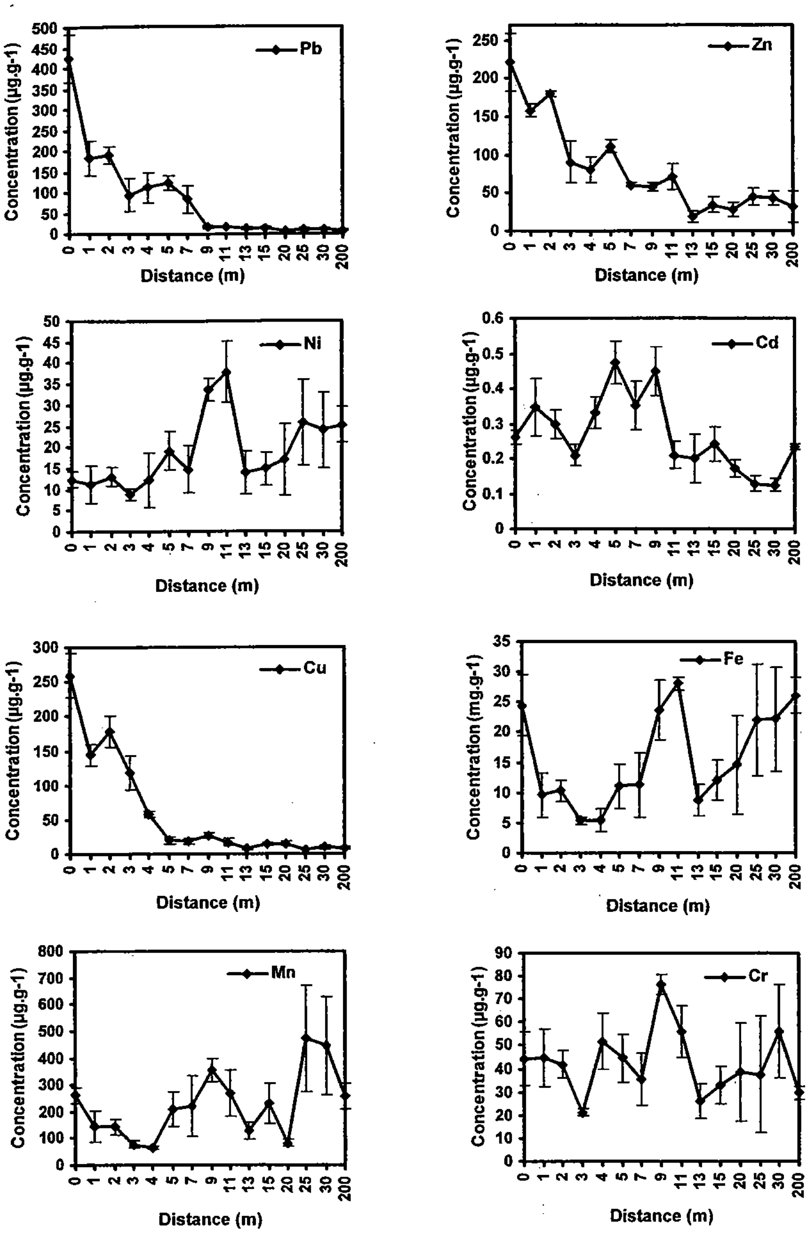

Fig. 2. Relationship between surface soil metal concentration and distance from road edge

edge, was found to reduce significantly concentrations of Pb and Fe. This indicates that a considerable amount of these two metals originate from atmospheric deposition. Aksoy *et al.* (1999) found that washing leaves of *C. bursa-pastoris* from suburban sites removes 35.8% of Pb, while washing leaves of *Poa annua* from the same sites removes only 13.5% of Pb. However, washing leaves of the two species from urban roadside sites removes about 50% of Pb. Washing leaves of date palms was found to remove 60% of Pb in a highway samples, 67% in urban samples, and 26% in rural samples (Al-Shayeb *et al.* 1995). Washing leaves of *N. oleander* was found to remove 30% of its Pb in samples from urban parks, 56% in those from urban roadside, and 10% in those from rural areas (Aksoy and Öztürk 1997). Washing leaves of *I. viscosa* removes about 33% of the Pb content and this is in agreement with some of the above-mentioned studies.

Conclusion

Concentrations of some metals in soil samples were found to decrease significantly with increasing distance from road edge (Pb = 539–2 $\mu g \cdot g^{-1}$, Cu = 321–4 $\mu g \cdot g^{-1}$, Zn = 295–6 $\mu g \cdot g^{-1}$). On the other hand, concentrations of all metals (except Cd) in plant samples were found to decrease significantly with increasing distance from road edge (Pb = 18–0.21 $\mu g \cdot g^{-1}$, Cu = 22.7–4.7 $\mu g \cdot g^{-1}$, Zn = 110–14.3 $\mu g \cdot g^{-1}$, Fe = 1.64–0.25 $mg \cdot g^{-1}$, Mn = 232–54.4 $\mu g \cdot g^{-1}$, Cr = 16.8–2 $\mu g \cdot g^{-1}$, Ni, 9.77–2.21 $\mu g \cdot g^{-1}$). This indicates roadside metal contamination. Washing leaves of *I. viscosa* reduces Pb and Fe

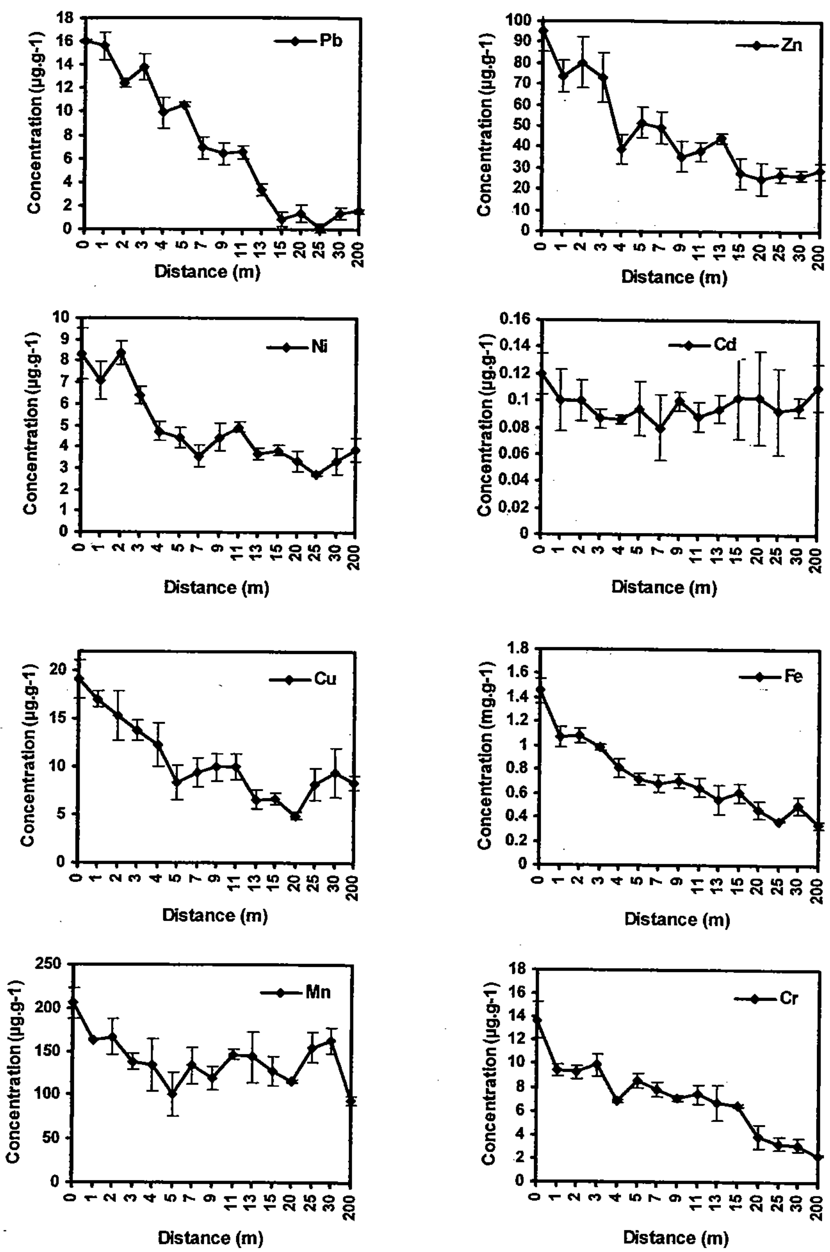

Fig. 3. Relationship between plant (*Inula viscosa*) metal concentration and distance from road edge

Table 4. Concentrations of metals (µg · g^{-1} ± SE) in new and old and in washed and unwashed leaves of *Inula viscosa* collected at a 10-m distance along Nablus–Ramallah Road in the West Bank (number of samples analyzed is 12)

	Leaves			Leaves		
	New	Old	*t*-test	Washed	Unwashed	*t*-test
Cd	0.12 ± 0.02	0.15 ± 0.00	ns[a]	0.14 ± 0.02	0.15 ± 0.02	ns
Pb	2.6 ± 0.46	8.50 ± 1.60	$p = 0.025$	1.40 ± 0.12	4.20 ± 0.2	$p = 0.005$
Cu	12.1 ± 1.2	11.8 ± 1.20	ns	14.5 ± 0.70	14.4 ± 1.1	ns
Zn	50.6 ± 8.4	61.7 ± 6.60	ns	45.7 ± 11.6	33.7 ± 6.4	ns
Fe	246.4 ± 6.5	616 ± 19.3	$p < 0.0001$	349.1 ± 26.0	715 ± 44.7	$p = 0.002$
Mn	56.6 ± 8.6	62.0 ± 15.9	ns	71.8 ± 10.2	51.2 ± 7.25	ns
Cr	1.83 ± 0.51	4.45 ± 1.0	ns	2.63 ± 0.33	3.87 ± 0.2	ns
Ni	6.13 ± 2.4	4.50 ± 0.7	ns	6.87 ± 1.70	5.47 ± 0.4	ns

[a] Not significant at $p < 0.05$.

Table 5. Concentrations of some metals in soil samples of the present study compared to those found in the literature

Reference	Soil type	Metal range ($\mu g \cdot g^{-1}$)			
		Pb	Cd	Cu	Zn
Present study	Roadside (0–200 m)	2–539	0.09–0.59	4–321	6–295
Olajire & Ayodele (1997)	Roadside (2–35 m)	71–339	0.18–1.28	20–57	22–68
Chronopoulos *et al.* (1997)	Roadside (0–20 m)	83–592	0.39–1.97	—	—
Sanchez-Martin *et al.* (2000)	Roadside (1–10 m)	18–353	0.07–0.64	—	—
Fatoki (1996)	Roadside (0–18 m)	—	—	2–19	1–120
Othman *et al.* (1997)	Roadside (5–80 m)	78–832	—	—	—
Swaileh *et al.* (2001)	Roadside (0–20 m)	89–245	0.25–0.73	18–30	95–170
	Forest (background)	7–20	0.04–0.20	8–23	67–110
Tiller (1992)	Dutch max. background	50	1	50	200
	Dutch critical value[a]	150	5	100	500
Ross (1994)	Toxic to plants	100–400	3–8	60–125	70–400

[a] Values set by Dutch authorities for investigation of a site for possible rehabilitation or restriction of land use.

Table 6. Concentrations of some metals in roadside plant samples of the present study compared to those found in the literature

Reference	Sample	Plant scientific name	Metal range ($\mu g \cdot g^{-1}$)			
			Pb	Cd	Cu	Zn
Present study	Roadside (0–200 m)	*Inula viscosa*	0.21–18	0.05–0.17	4–23	14–110
Aksoy & Öztürk (1997)	Roadside, urban, rural	*Nerium oleander*	2.6–28	0.02–0.72	3–6	8–21
Djingova *et al.* (1999)	Industrial	*Populus nigra*	3.3–91	0.49–6.6	4–71	66–650
Aksoy *et al.* (1999)	Urban	*Capsella bursa-pastoris*	8–57	0.45–1.07	9–26	53–200
Kabata-Pendias and Pendias (1992)	Normal range in plants	—	—	0.5–0.1	5–30	27–150
Reeves *et al.* (1995)	Phytotoxic range	—	30–300	5–30	20–100	100–400

concentrations significantly, indicating a significant aerial deposition of these metals. In addition, old leaves contained significantly higher Pb and Fe than new ones. This confirms aerial depostion and indicates leaf uptake. Concentrations of metals in *I. viscosa* leaves showed less fluctuations than those in soil samples. In addition, *I. viscosa* meets the basic criteria put by Witting (1993) for the selection of a species as a biomonitor for metal pollution. These include abundance in the study area, a wide geographical range, easy to sample and identify, and be able to differentiate between airborne and soil borne metals. Therefore, *I. viscosa* can be a useful biomonitor for roadside metal pollution in Palestine and other Mediterranean countries.

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