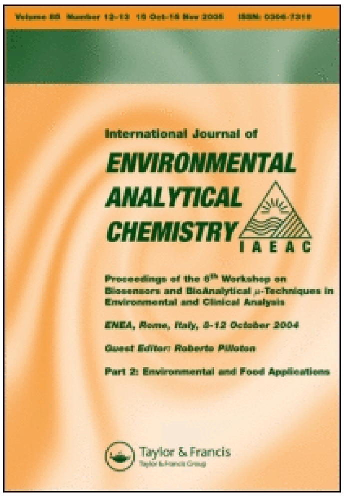

International Journal of Environmental Analytical Chemistry
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713640455

Sources of Soil and Plant Contamination in an Urban Environment and Possible Assessment Methods

M. Sáňka[a]; M. Strnad[b]; J. Vondra[a]; E. Paterson[c]
[a] Czech Institute for Nature Conservation, Brno, Czech Republic [b] Czech Geological Survey, Brno, Czech Republic [c] Macaulay Land Use Research Institute, Craigiebuckler Aberdeen, Scotland

To cite this Article Sáňka, M. , Strnad, M. , Vondra, J. and Paterson, E.(1995) 'Sources of Soil and Plant Contamination in an Urban Environment and Possible Assessment Methods', International Journal of Environmental Analytical Chemistry, 59: 2, 327 — 343
To link to this Article: DOI: 10.1080/03067319508041338
URL: http://dx.doi.org/10.1080/03067319508041338

Intern. J. Environ. Anal. Chem., Vol. 59, pp. 327–343
Reprints available directly from the publisher
Photocopying permitted by license only

SOURCES OF SOIL AND PLANT CONTAMINATION IN AN URBAN ENVIRONMENT AND POSSIBLE ASSESSMENT METHODS

M. SÁŇKA[1], M. STRNAD[2], J. VONDRA[1] and E. PATERSON[3]

[1]Czech Institute for Nature Conservation, Lidicka 25/27, 657 20 Brno, Czech Republic, [2]Czech Geological Survey, Leitnerova 22, 658 69 Brno, Czech Republic, [3]Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, Scotland

(Received, 29 November 1993; in final form, 20 June 1994)

A survey was carried out in the city of Brno, Czech Republic in order to determine the levels and sources of soil and plant contamination and the possible implications for human health. A group of 136 topsoil and plant samples were taken in a defined sampling pattern, both in urban (in the year 1991) and suburban (1992) areas, paying particular attention to traffic density and intensity of land use. Samples were analysed for the contents of six heavy metals (Cd, Cu, Cr, Ni, Pb, Zn) and polycyclic aromatic hydrocarbons. The main soil characteristics were also determined (pH, CEC, C_{ox}).

Traffic influence indices (TII) were calculated for each locality based on the traffic density and micro climatic conditions. Soil pollution indices (SPI) and plant pollution indices (PPI) were defined as a loading of a group of toxic metals relative to acceptable upper limits and were used as a general measure of the soil and plant burden at a particular site.

There were significant differences between the level of pollution in urban and suburban areas particularly for Pb, Cr and Ni in plants.

Traffic was found to be the major source of pollution by Pb, Zn and Cu in the urban survey and significant correlations were found between soil Pb x TII and SPI x TII in urban area. No such relationships were found for the suburban samples.

KEY WORDS: Heavy metals, PAHs, soil contamination, plant contamination, urban environment, assessment methods.

INTRODUCTION

As the number of people living in towns and cities has increased, larger human populations are being exposed to the negative effects of the urban environment. Sources of pollution can vary according to specific industrial, geographical, geological, climatic and sociological conditions but in virtually all cases road traffic is one of the most important ones and it influences all parts of the environments. In this connection, soil occupies a special position. In pollution research soil is mainly considered as a medium of plant growth and agriculture production but, in urban conditions, changes in the chemical nature of the soil can lead to adverse interactions with building materials, toxicity to soil flora and fauna and influence exposure of the population particularly young children, to toxic substances. Because of its properties, soil can also serve as a medium for monitoring of long term effects of environmental pollution in towns. Of the various toxic substances in the urban environment lead is considered to be the most hazardous. Although its harmful effects are still debated[6], some authors have presented evidence of its neurotoxicity especially for children[3]. About 75% of the lead content in petrol is emitted to the atmosphere[8] which creates the main source of lead in the urban environment. This source is responsible for about 75% of the lead in the atmosphere in UK[19]. Of the emitted lead 8% is removed in drainage waters, 6% is deposited in the first 50 m adjacent to a motorway and 86% is dispersed in the atmosphere[11]. Even the relatively small proportion of lead which is deposited along roads can bring about lead deposition rate over 1 $mg.m^{-2}.day^{-1}$ on smooth surfaces and 8 times higher rate on rough leaf and soil surfaces[1]. At such deposition rates lead concentrations can reach several hundreds of $mg.kg^{-1}$ in soils and several tens of $mg.kg^{-1}$ in plants, with the highest concentration at a distance of about 1.5 m from the road and declining to background over a distance of about 100 m or more, depending on traffic density and other factors[4].

The sources and distribution of other potentially toxic elements like Cd, Cr, Cu, Ni, Zn in the urban environment have also been studied[2,12,15,21]. Specific industrial sources can significantly influence deposition of these elements in towns but traffic is also an important source. Muschak[16] measured average emissions of elements on a main thoroughfare from the abrasion of tyres, brake linings and street surface itself (Table 1).

Other traffic-related sources of pollutants are wear and tear of car components and engines as well as combustion and release of lubricating oil. In the top soil along a road carrying 120,000 vehicles per day substantially elevated contents of risk elements (Cr 209; Ni 314; Cu 46; Zn 940; Cd 9.1 $mg.kg^{-1}$, [20]) were found.

Large amounts of elements can come from the weathering of materials, e.g. although Fergusson and Kim[7] reported a decrease in the lead content of dust after heavy rain the Zn content increased, probably by washing of weathered material from galvanised iron roofs.

Another important group of pollutants in towns are polycyclic aromatic hydrocarbons (PAHs), which can cause mutagenic and carcinogenic effects[14]. They originate from pyrolytic reactions during combustion of organic matter and Grimmer[10] has estimated that 13% of air borne PAHs arise from road traffic. In towns with higher traffic densities this number is probably much higher. According to Yang *et al*[23], traffic is the main source of PAHs in towns and the soil concentration of PAHs decreases with increasing distance from the road but is still significant at a distance of 15 m. PAHs with more than four aromatic rings were deposited close to the roadway due to their predominant particulate form. Hewitt and Rashed[11] found that only about 1% of the PAHs with the lowest molecular weight was deposited on the grass and soil adjacent to motorway but up to 30% of that with high molecular weight.

Brno, the second largest city in the Czech Republic with about 400,000 inhabitants is an example of a city, without any significant single industry, where traffic plays a major role in pollution of the environment. The situation in Brno is particularly problematic

Table 1 Emission of elements on main thoroughfare ($g.km^{-1}$ $year^{-1}$).

Abrasion source	*Pb*	*Cr*	*Cu*	*Ni*	*Zn*
Tyre	506	84	115	80	285
Brake linings	61	115	1759	429	4
Street surface	1486	5119	743	17040	2388

since the main thoroughfares pass through the very centre of the town. In this study we have tried to distinguish the importance of individual pollutants in soil and plant pollution as well as quantify differences between urban and suburban areas, exposed to different traffic density.

MATERIALS AND METHODS

Sampling scheme

54 sampling sites in the urban area and 84 sampling sites in the suburban area were chosen for soil and plant sampling in two consecutive years, 1991 and 1992. The sites were selected by collaboration between city planners, soil scientists and civic representatives in order to meet the following criteria: (a) to include all main traffic networks and cross-roads, (b) to assess frequently visited public places, (c) to allow comparison with the background localities, (d) to be covered by grass to allow plant analysis and (e) to cover the whole town area. Each sample was taken from a rectangular area of 2 × 5 m from which about 25 individual samples were bulked to give representative average sample. Soils were sampled to the depth of 0.1 m with a small auger. Plants (grass in all cases) were taken without roots from the same places as the soil. In both the urban and suburban areas the samples were divided into two categories: those influenced by traffic and these from relatively clean areas. The samples influenced by traffic were obtained with the 2 × 5 m rectangle parallel with road edge at a distance of 1 m. In both years sampling was carried out during one week at the beginning of July with stable weather conditions.

Analytical

Soil samples were dried at room temperature, sieved and homogenised. Basic soil characteristics were measured by common methods: soil pH was determined using a 1:4 solid/liquid ratio in 0.2M KCl, organic carbon was determined by dry combustion and the cation exchange capacity measured by saturation with NH_4^+ and colorimetric determination of the NH_4^+ content. The contents of Cd, Cr, Cu, Ni, Pb and Zn were analysed in 2M HNO_3 extract[18] using atomic absorption spectroscopy (PE 5100 PC instrument). A set of control samples was analysed independently in three laboratories.

Contents of 16 individual PAHs (according to EPA list) were determined[13].

Plant samples were analyzed without previous washing. 5 g of material were oven-dried at 105°C and burnt at 550°C. The ash was boiled and dissolved in 10 ml of 10 M HNO_3. After filtering, destilled water was added to the content of 50 ml. Contents of Cd, Cr, Cu, Ni Pb and Zn were analysed by AAS technique (PE 5100 PC instrument).

Processing of results

The measured soil characteristics, contents of potentially toxic elements in both plants and soils and polyaromatic hydrocarbons in soils were processed by means of regression analysis with special regard to the influence of traffic. For that purpose, indices of soil exposure to the influence of traffic (TII = traffic influence index) were calculated for each sampling point using the formula:

$$TII = MC \, . \, TD$$

where

MC = micro climatic conditions of a locality given by its profile which influences dispersion of exhaust fumes. The index was evaluated according to the height of buildings (vegetation) and their distance from roads.
MC = 0.25 - open localities without any buildings or vegetation along side the road
MC = 0.50 - low buildings on one side ofthe road or on both sides but very low and at some distance
MC = 0.75 - high buildings along one side of the road or low buildings on both sides
MC = 1.00 - high buildings, very near along both sides of the road
TD = traffic density given by the number of all vehicles passing during 24 hours (in tenths of thousands). This number was taken from the official list.

For the localities without any influence of traffic, the TII was estimated to be 0.01.

For the whole soil heavy metal burden, the soil pollution index (SPI) and plant pollution index (PPI) were calculated for each locality. The relative values of element contents with regard to the limit (= 100%) were calculated at first. These values were summed up and expressed again as a percentage from the sum of relative limit values (= 600% because of 6 elements) using the formulas:

$$SPI = 1 / n \, . \sum_{i=1}^{n} . \; 100 \, . \, \frac{VS_i}{LS_i} \quad \text{and} \quad PPI = 1 / n \, . \sum_{i=1}^{n} . \; 100 \, . \, \frac{VP_i}{LP_i}$$

where:
n = number of elements
VS (VP) = content of an element in the soil (plant) ($mg.kg^{-1}$)
LS (VP) = limit value of an element content in the soil (plant) ($mg.kg^{-1}$) (Table 2)

RESULTS AND DISCUSSION

Statistical summaries description of the results obtained in the soil and plant survey in the Brno urban and suburban area are presentes in Tables 3 and 4. The simplest assessment of results would be to compare them with the background contents in soils ans plants. However this can be rather distorting because of the wide range of background contents, sometimes exacerbated by the use of various analytical methods. Evaluation with the help of limit values for agricultural soils and plants can also be inappropriate for urban soils because the agricultural limits are constructed with respect

Table 2 Limit values of risk elements and PAHs in soils and plants ($mg.kg^{-1}$ d.m.).

	Cd	*Cr*	*Cu*	*Ni*	*Pb*	*Zn*	*PAHs**
Soil**	0.4	40.0	30.0	15.0	50.0	50.0	1.0
Plant***	1.3	21.5	215.0	21.5	21.5	1075.0	–

* upper value of PAHs background range in soils
** limits for 2M HNO_3 extract in light soils
*** recalculated from limits for fresh matter of forage

Table 3 Descriptive statistics for urban area (no. of samples = 54).

	soil											plant						
	Pb	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PAH*	*pH*	C_{ox}	*T*	*SPI*	*Pb*	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PPI*
Mean	50.15	0.49	6.87	8.03	79.89	27.53	3.73	7.16	2.37	23.05	90.80	10.70	0.11	11.27	6.33	38.61	8.55	24.57
Median	31.75	0.29	6.03	7.79	54.00	18.77	1.48	7.30	2.19	22.60	69.55	9.00	0.09	6.90	3.40	34.15	8.65	16.78
Standard D	45.38	0.58	2.69	1.98	63.48	21.17	6.73	0.56	0.91	6.84	62.33	7.66	0.09	11.13	10.88	17.83	4.48	20.46
Kurtosis	8.09	9.31	3.54	3.14	2.02	1.34	29.26	10.88	3.39	0.30	4.35	18.00	5.32	7.82	34.45	0.95	–0.47	8.74
Skewness	2.53	2.86	1.93	0.97	1.43	1.39	4.92	–3.36	1.44	0.67	1.84	3.68	2.05	2.62	5.50	1.08	0.43	2.71
Minimum	13.90	0.01	4.23	3.76	11.05	4.85	0.17	4.84	0.68	10.80	21.46	2.30	0.01	3.00	1.21	11.00	1.90	7.34
Maximum	257.40	3.01	15.76	15.65	310.00	95.00	45.75	7.58	5.84	42.80	344.03	53.10	0.45	61.00	76.82	95.10	19.25	118.48

Table 4 Descriptive statistics for suburban area (no. of samples = 82).

	soil											plant						
	Pb	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PAH*	*pH*	C_{ox}	*T*	*SPI*	*Pb*	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PPI*
Mean	23.09	0.30	6.18	8.26	55.05	16.55	1.54	7.00	1.87		59.36	0.94	0.06	0.52	0.88	35.36	4.71	3.55
Median	17.50	0.24	5.19	8.15	36.10	11.35	0.61	7.16	1.78		46.90	0.80	0.05	0.40	0.80	30.75	4.20	3.19
Standard D	17.01	0.22	4.14	2.99	62.63	22.03	2.82	0.52	0.83		42.24	0.71	0.06	0.50	0.42	19.64	2.24	1.57
Kurtosis	7.17	15.73	33.10	4.01	29.44	28.91	13.03	6.15	9.20		13.65	6.89	18.80	12.86	3.68	16.05	7.09	4.32
Skewness	2.66	3.46	5.09	1.11	4.67	5.19	3.48	–2.46	2.25		3.36	2.30	4.03	3.25	1.65	3.05	2.18	1.88
Minimum	4.80	0.03	2.26	1.14	13.80	3.73	0.01	4.90	0.19		22.04	0.05	0.02	0.10	0.06	13.10	1.60	1.54
Maximum	96.60	1.53	35.80	21.10	492.50	149.90	16.47	7.54	6.11		286.69	4.10	0.44	3.20	2.50	155.10	14.30	9.57

Table 5 Percentages of sampled localities having higher contents of pollutants than limit values (in PAHs higher than upper level of background range values; in SPI and PPI percentage of samples with higher value than 100).

	Pb	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PAHs*	*SPI/PPI*
Urban soil	33	33	0	2	52	35	57	33
Urban plant	4	0	13	4	0	0	0	2
Suburban soil	6	12	0	5	32	6	34	11
Suburban plant	0	0	0	0	0	0	0	0

to possible uptake of pollutants by agricultural plants and the limits for plants are constructed with respect to toxicity for animals. There is limited knowledge about highest acceptable contents of risk elements in urban soils. The UK limit values fror parks, playing fields and general open space (15 $mg.kg^{-1}$ of Cd, 1000 $mg.kg^{-1}$ of Cr and 2000 $mg.kg^{-1}$ of Pb;[5]) are tentative values used as guidance when contaminated land is to be redeveloped i.e. a change in use but probably much lower values can have chronic adverse effects on human population in towns. However in the absence of other guidance the Czech limit values for agricultural soils and plants (Table 2) were used for assessment of results in this study. The percentages of samples with higher values than these limits are given in Table 5.

Comparison of Tables 3, 4 and 5 shows that there are much higher contents of elements and PAHs in soils in the urban area with the exception of Ni and Cr where the contents are more or less the same. The difference is greatest for lead and PAHs. Even bigger differences between the urban and suburban areas can be seen in the plants where especially lead but also other elements, except Zn, had considerably higher contents in the urban area. Plants were sampled over two consecutive years and, although this may contribute to the differences between urban and suburban samples, it can still be said that plant pollution in the urban area is much higher.

In order to illustrate the influence of traffic the average contents and confidence intervals of pollutants and soil and plant pollution indices are shown in Figure 1. for localities influenced by traffic and those that are relatively untouched. In the urban area significantly higher values of Pb, Cd, Cu, PAHs and SPI in soil and Pb, Cr, Ni, Cu and PPI in plants were found on localities under the traffic influence. Considerably smaller effects were recorded in the suburban area where only soils Pb and Zn had higher contents in traffic-affected areas. Plant pollution in the suburban area seems not to be influenced by traffic very much, probably because of the relatively low traffic density but also, perhaps, because of the masking effects of other possible sources of pollution. The influence of traffic on the contents of Pb, Cr and Ni in plants shown in Figure 3 is rather masked by the fact that these metals had much higher contents in localities without traffic in the urban area than in localities with traffic in the suburban area (Figure 1). This could be because of the higher contents of these elements in dust found in the centre of town.

For urban and suburban areas we can see the influence of traffic in more detail in Figure 2 for soils and Figure 3 for plants. There are five classes of traffic influence indices on the x axis, with the influence of traffic increasing from class 1 to class 5. Although the confidence intervals ($p = 0.05$) are small in class 1 because of lower variability between samples, the larger number of locations also contributes. The variability for localities influenced by traffic is larger and when combined with the relatively small number of analyses confidence limits are larger. In the soils only Pb, Zn,

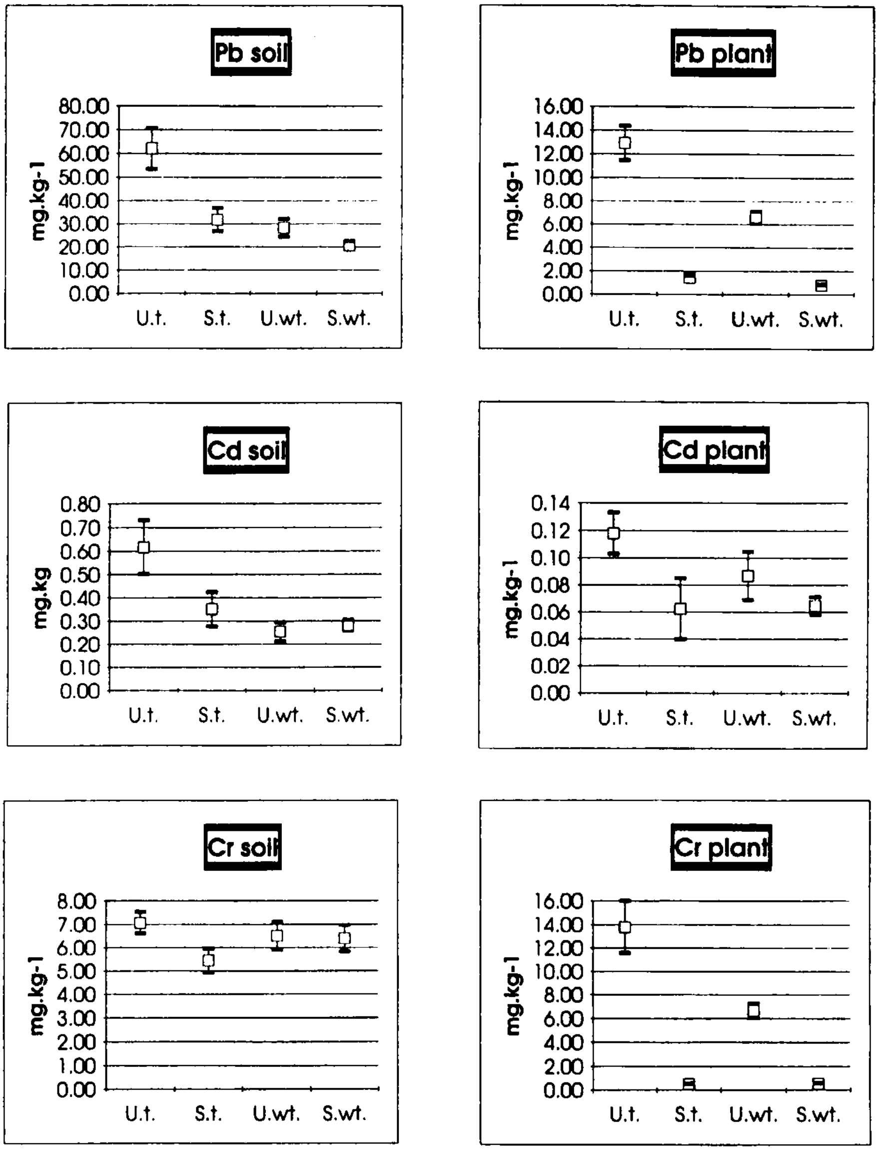

Figure 1 Means and confidence intervals ($p = 0.05$) for contents of elements, PAHs and soil/plant poll. indices in soils and plants according to coditions: U.t. -localities in urban ar. under the traddic infl.; S.t. -localities in suburban area under the traffic influence; U.wt. -localities in urban area without the traffic infl.; S.wt -localities in suburban area without the traffic infl.

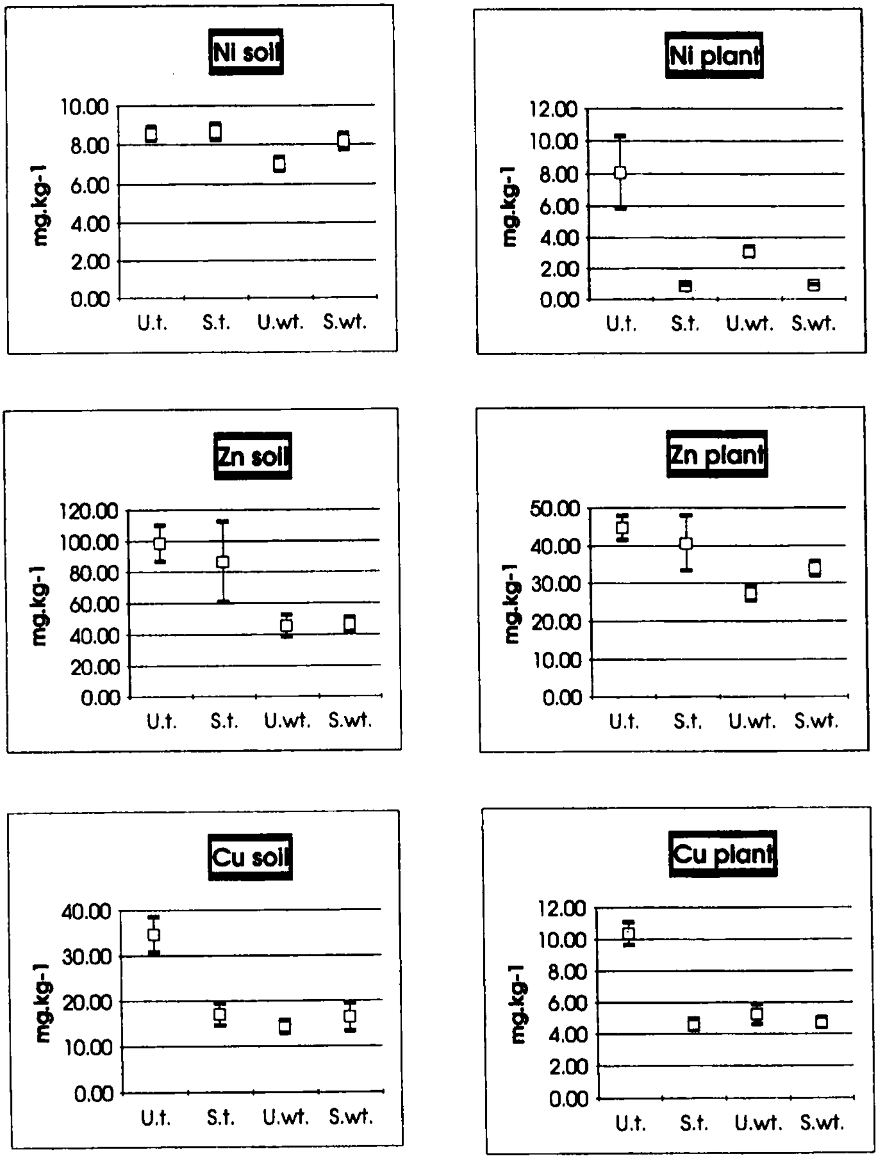

Figure 1 (*cont.*)

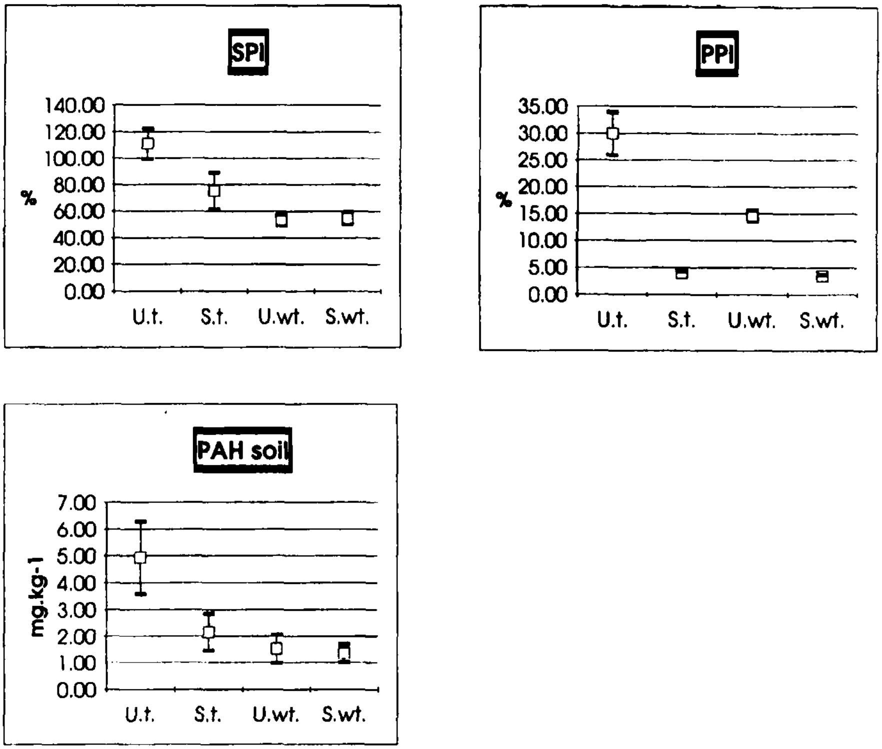

Figure 1 (*cont.*)

Cu and SPI have statistically significant differences between class 1 and classes 4 and 5. This means that a significant influence of traffic can only be found when the number of vehicles is higher than 10,000 per day (or slightly lower when combined with unfavourable climatic conditions - high buildings or vegetation along the road). The same situation can be seen in the case of plants but without any significant difference in PPI.

Processing of results by correlation analysis showed similar results (Table 6). In the suburban area only the lead contents of plants are dependent on traffic as opposed to the urban area where contents of Pb, Zn, Cu, PAHs and SPI in soils and contents of Pb, Zn, Cu and PPI in plants have significant correlations with TII. Contents of Cd, Cr and Ni in plants in the urban area also show some dependence although it is less significant.

Table 6 Correlation coefficients between traffic influence index and contents of elements in soils and plants in urban and suburban area.

TII	*Pb*	*Cd*	*Cr*	*Ni*	*Zn*	*Cu*	*PAHs*	*SPI*	*PPI*
Urban soil	0.58**	0.26	0.07	0.23	0.52**	0.56**	0.44**	0.53**	–
Urban plant	0.58**	0.28*	0.35*	0.30*	0.60**	0.59**	–	–	0.48*
Suburban soil	0.19	– 0.02	– 0.08	0.09	0.09	0.00	0.11	0.07	–
Suburban plant	0.41**	0.00	0.02	– 0.02	0.09	0.05	–	–	0.17

*p = 0.05; **p = 0.01.

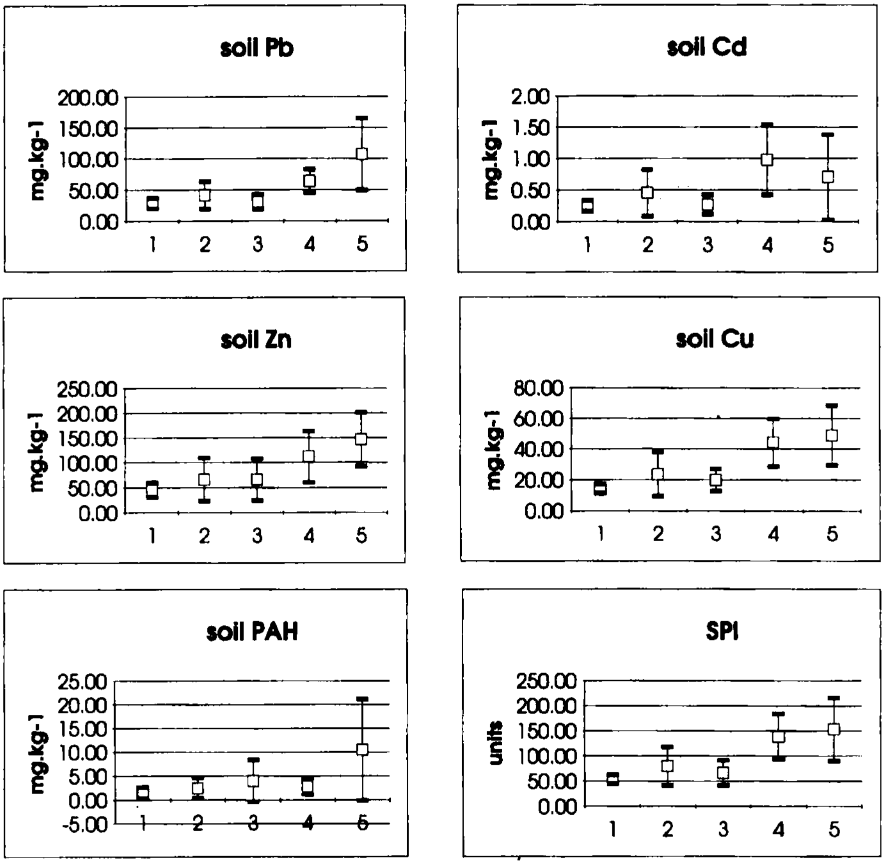

Figure 2 Means and confidence intervals for contents of elements (including soil pollution index) and P, n soils according to total traffic influence index (TIIt)
1 =TIIt 0.01
2 = TIIt 0.02 – 5.0
3 = TIIt 5.1 – 10.0
4 = TIIt 10.1 – 15
5 = TIIt 15+

Among the main soil properties only organic matter (C_{ox}) seems, to some extent, influence the 2M HNO_3 extractable content of some elements with statistically significant relationships between C_{ox} and the contents of Cd, Pb, Cr, Zn, and Cu, the highest being with Cd (r = 0.48). This is in agreement with the results of other authors although the highest affinity for the organic matter fraction has been found for Cu[9]. There is also a slight relationship with cation exchange capacity but this characteristic is probably influenced mostly by the organic matter content since most of the soils are calcareous loams. This is also the reason why no relationship was found between soil pH and the contents of potentially toxic elements since almost all the soils had pH > 7.

Significant correlation (r = 0.67) was found between the PAHs and Pb contents in the soil which supports the suggestion that these pollutants arise from a common source. However in some localities their contents varied either because of a different history of traffic exposure (decomposition of PAHs) or because of other possible sources of

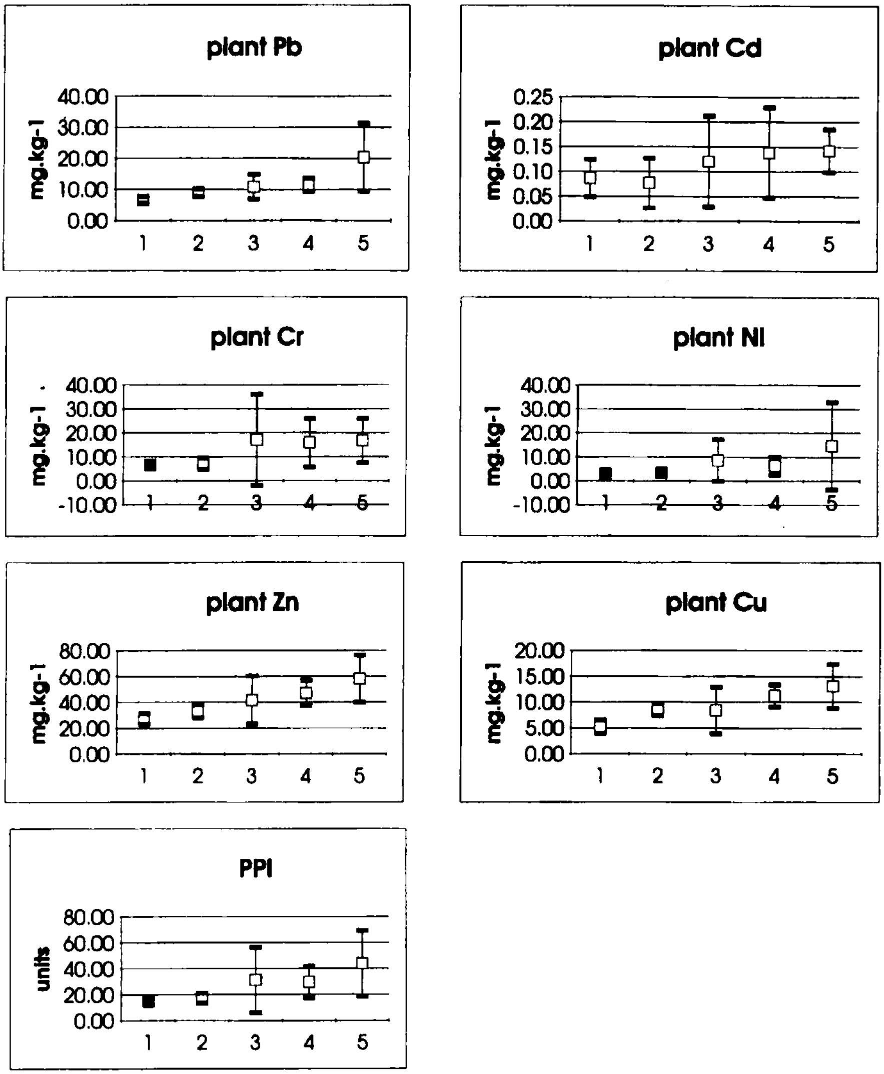

Figure 3 Means and confidence intervals for contents of elements and PAH in plants (including plant pollution index) according to total traffic influence index. Classes of TIIt as in soils.

pollution. Local heating and burning of waste in gardens in suburban area may cause elevated PAHs contents in soils. Significant correlation was also found between Pb × Zn (r = 0.53); Pb × Cu (r = 0 62); Cd × Zn (r = 0.63); Cd × Cu (r = 0.56); Cr × Cu (r = 0.66) and Cu × Zn (r = 0. 54).

In plants positive correlation exists among all observed element contents the most important being between Pb × Cr (r= 0.69); Pb × Cu (r = 0.72); Pb × Ni (r = 0.57); Cr × Ni (r = 0.75) and Cr × Cu(r = 0.60).

Only low relationships were found between the soil and plant contents of individual elements with the exception of Cd (r = 0.53) which is known to form a relatively large

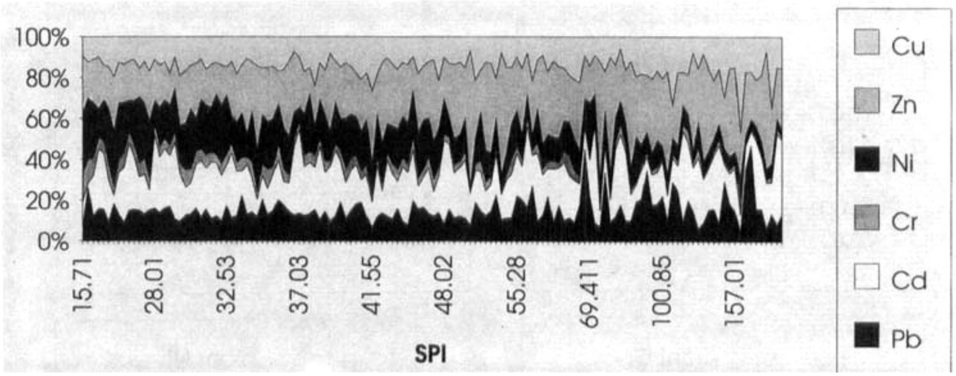

Figure 4 Relative share of pollution indices for individual elements in the total soil pollution index. Ordered ascendingly according to SPI.

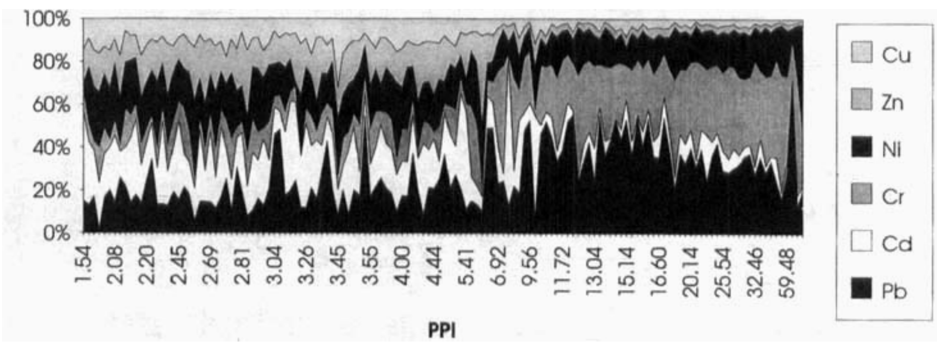

Figure 5 Relative share of pollution indices for individual elements in the total plant pollution index. Ordered ascendingly according to PPI.

proportion of exchangeable fraction in soil and is, therefore readily plant available[22]. These results are consistent with deposition of pollutants on plant surfaces in conditions with high air pollution rather than uptake from the soil itself.

The soil and plant pollution indices (SPI, PPI) were developed to take account of the whole heavy metal burden of each locality. It should be noted, however, that there is a certain "levelling out" of results i.e. the limit of one or two elements can be exceeded and the SPI or PPI may still be under 100 provided that the contents of other elements are low enough. Nevertheless this gauge does give a general indication of the pollution climate at a given locality and can provide a graphical indication of areas where there are increased pollution pressures on the environment. An example based on the Brno survey is given in Figure 7.

The relative importance of individual elements in the total SPI and PPI is given in Figures 4 and 5 for each locality in ascending order on the X-axis. The SPI is dominated by Zn, Cd, Cu and Pb for all the sampling sites. There is a clear change in the importance of the individual elements dominating the SPI in "clean" and polluted sites. As the SPI increases, the importance of Cu, Zn and Pb increases and that of Cr, Ni and Cd decreases. Ni is the extreme example of this trend in that it decreases from a substantial contribution in "clean" localities to virtually zero in highly polluted ones.

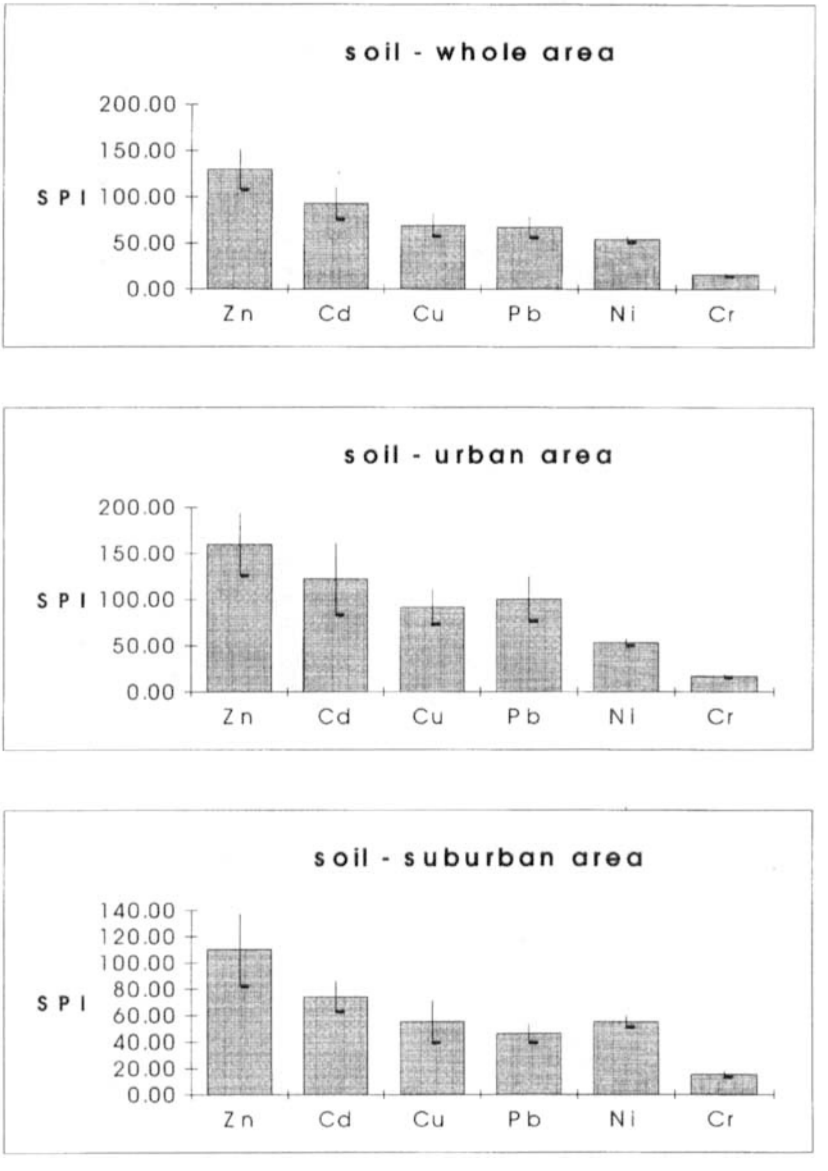

Figure 6 Aritmetic means and confidence intervals (p = 0.05) of soil and plant pollution indices for individual elements according the area.

The plant pollution index demonstrates a quite different pattern (Figures 5 and 6). Overall, Pb, Ni and Cr contribute a substantial proportion but with marked difference between clean and polluted localities. It is clear that clean localities are concentrated in the suburban area with a more even representation of elements in the PPI while the polluted sites are mainly in the urban area where Pb, Ni and Cr contribute to the PPI.

Although the pollution indices developed in this study have been used successfully in a relative way to compare sites and areas their absolute values depend on the actual

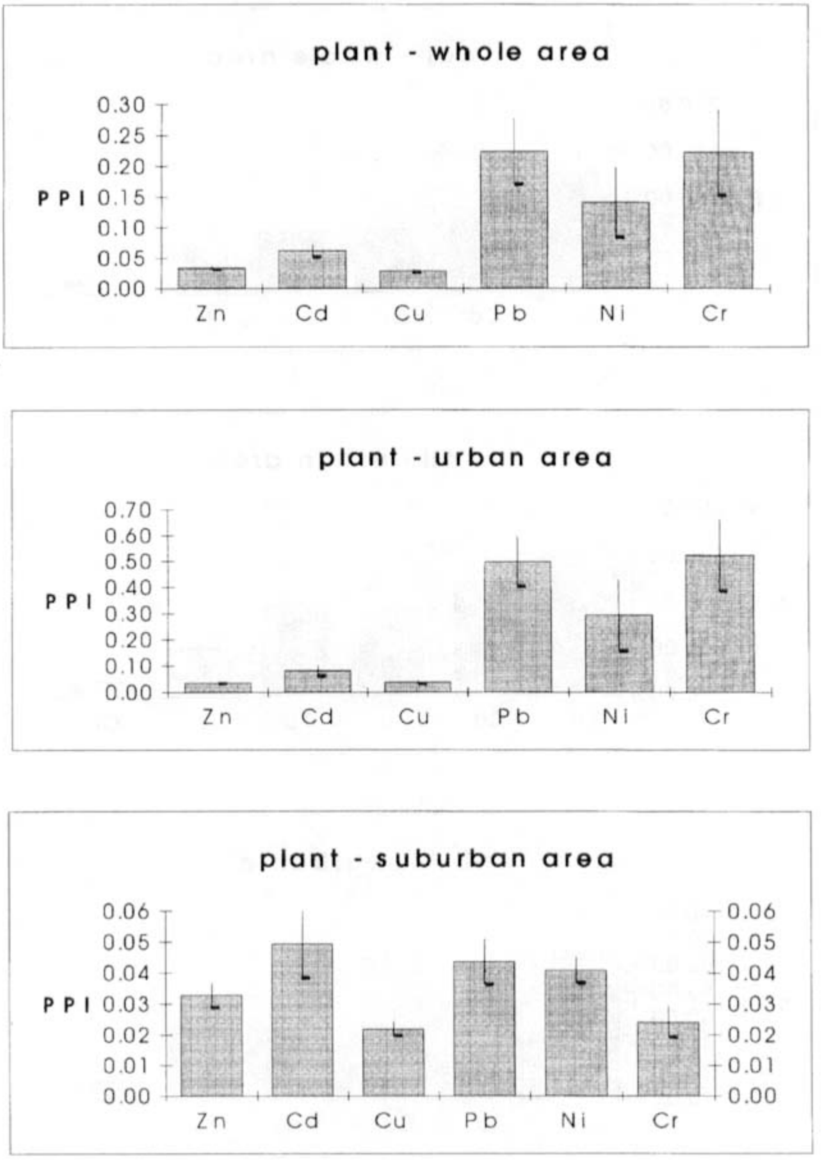

Figure 6 (*cont.*)

limits selected for each element. In the case of urban soils the selection of suitable limits is difficult. Commonly, agricultural or horticultural limits are used but other methods have been proposed. Simms and Beckett[17] calculated threshold values of Pb and Cd concentrations in soils based on possible pathways from soil to man and on human body burden of these elements which could cause health problems. They consider contents under 500 mg.kg^{-1} of lead and 3 mg.kg^{-1} of cadmium as safe. From this point of view the results from Brno do not pose any direct danger to the human population even bearing in mind that total contents would be higher than those obtained using 2M HNO_3 extraction.

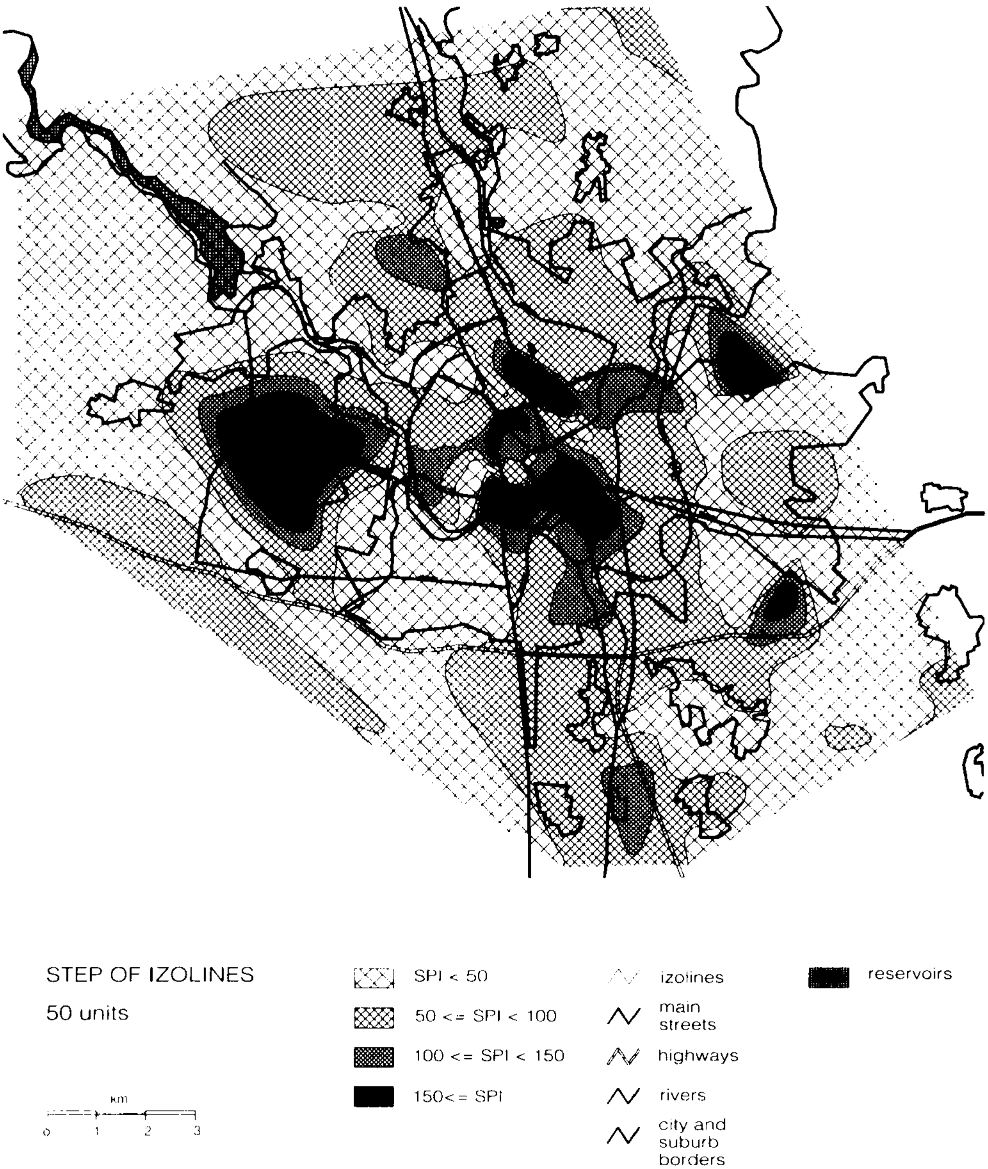

Figure 7 Soil Pollution Index (units) Brno urban suburban area.

This approach could obviously be applied to other elements as well for the urban environment. On the other hand many cases of breaching of the Czech limit values for soils and plants in the urban area merit continuing observation and working out limits more appropriate to urban conditions.

In towns like Brno with no big industry lead pollution from traffic is considered to be the most serious inorganic pollutant. In this study, comparison with limit values for soil ranked lead at third place in urban and four place in suburban areas. Zinc takes first place but, in this case, the limits are set by its phytotoxicity, and this is not of such importance in places which are not being used for agricultural production.

CONCLUSIONS

Significantly higher contents of Pb, Cd, Cu, Zn and PAHs in soils and Pb, Cd, Cu, Cr and Ni in plants were found in the urban area compared with the suburban one.

Traffic proved to be an important source of pollution in the urban area and in localities with traffic density higher than about 10,000 vehicles a day. This influence was most obvious in the case of Pb, Zn and Cu both in soils and plants. Traffic is also responsible for pollution of soils by PAHs although their elevated contents can be caused by other local sources as well.

Influence of soil properties on the level of pollution is very low.

Relationship between contents of elements in soils and plants is generally low in urban conditions, the highest being in Cd.

The use of soil and plant pollution indices showed that Zn, Cd, Cu and Pb were the most important pollutants in soils and Pb, Ni and Cr in plants but probably still without any direct danger to the human population in the town. The results substantiate the use of plant materials for the measurement of urban environmental pollution over the medium term (one year) whilst the soil results may be taken as a longer term cumulative indicator. However more accurate limit values of risk element contents in soils and plants for urban environment should be specified.

Acknowledgments

Partial support for this study was provided by Brno Town Hall with particular thanks to Mrs. Vyslouzilova. Thanks are also due to the Central European University who financed the senior author's stay at the Macaulay Land Use Research Institute where many of the results were processed.

References

1. E. A. Ali and M. M.Nasralla. *Proceedings from the conference Heavy Metals in The Environment,* (Athens September 1985), Vol. **1**, pp. 147–149.
2. E. M. Bridgcs, *Soil Use Manag.* **5**, 91–100 (1989).
3. D. Damm, *Proceedings from the conference Heavy Metals in the Environment,* (Edinburgh, Sept. 1991), Vol. **1**, pp.
4. B. E. Davies, *Applied soil trace elements.* (John Wiley & Sons, New York, 1980), 482 p.
5. Department of the environment (DoE), *Guidance on the assessment and redevelopement of contaminated land.* Interdepartmental committee on the redevelopment of contaminated land. DoE, London (1987).
6. C. B. Ernhart and S. Scarr, *Proceedings from the conference Heavy Metals in the Environment,* (Edinburg, Sept. 1991), Vol. **1**, pp. 156–158.
7. J. E. Fergusson and N. D. Kim, *Sci. Total Environ.*, **100**, 125–150 (1991).
8. H. A. Foner, *Sci. Total Environ.*, **93**, 43–50 (1990).
9. S. M. Gentry, L. Andreassen and P. Birch, *Seesoil,* **5**, 107–126 (1987).
10. G. Grimmer, *GIT Fachz. Labor.*, **36**, 12–21 (1992).
11. C. N. Hewitt and M. B. Rashed, *Sci. Total Environ.*, **93**, 375–384 (1990).
12. Y. B. Ho and K. M. Tai, *Environ. Pollut.*, **49**, 37–51 (1988).
13. I. Holoubek, J. Paasvirta, P. Maatela, M. Lahtipera, I. Holoubkova, P. Korinek, Z. Bohacek and J. Caslavsky, *Toxicol. Environ. Chem.*, **25**, 237–254 (1989).

14. J. Jacob, W. Karcher and P. J. Wagstaffe, *Fresenius Z. Anal. Chem.*, **317**, 101–114 (1984).
15. W. Lux, B. Hintze and H. Pienning, *Proc. Congr. ISSS* (Hamburg, 1986), Vol. II, pp. 376–377.
16. W. Muschak, *Sci. Total Environ.*, **93**, 419–431 (1990).
17. D. L. Simms and M. J. Beckett, *Sci. Total Environ.*, **65**, 121–134 (1987).
18. UKZUZ, Unified working procedures: Determination of harmful substances in soil by 2M HNO_3 solution, Internal methodology, Central Checking and Testing Institute in Agriculture, Czech Republic, (1984).
19. M. L. Williams, *Sci. Total Environ.*, **93**, 1–8 (1990).
20. N. I. Ward, *Sci. Total Environ.*, **93**, 393–401 (1990).
21. M. H. Wong, *Agricult., Ecosyst. Environ.*, **13**, 139–149 (1985).
22. X. Xian, *Plant and Soil.*, **113**, 257–262 (1989).
23. S. Y. N. Yang, D. W. Connell, D. W. Hawker and S. I. Kayal, *Sci. Total Environ.*, **102**, 229–240 (1991).