Metal content of surface soils in parks and allotments from three European cities: initial pilot study results

Andrew Hursthouse, Donna Tognarelli, Peter Tucker, Franco Ajmone Marsan, Chiara Martini, Luis Madrid, Fernando Madrid and Encarnacion Diaz-Barrientos

Abstract

A pilot study of metal content and basic soil properties was undertaken in a number of parks and allotments in the cities of Glasgow, UK, Torino, Italy, and Sevilla, Spain. Between 40 and 60 samples were collected from each city, with soil from two depths. The maximum metal contents (aqua regia) found were 698 mg/kg Cu; 1004 mg/kg Zn; 300 mg/kg Ni; 356 mg/kg Cr and 7051 mg/kg Pb. Variability of metal content showed similar patterns across all cities, with a number of outlier data points. Surface and sub-surface samples were comparable within sites. Cu, Zn and Pb levels appeared to contain most variability and extreme data points, while Ni and Cr were more homogeneous. The data support previously published observations of anthropogenic association (Cu, Zn and Pb) and natural sources (Ni and Cr), found in urban environments influenced by diffuse pollution. Within the Glasgow data, differences in the variability of metal content in park and allotment soil are not dramatic, but do reflect the influence of different agromonic activities. The study has provided baseline information for ongoing pan-European urban soil research funded through the EU.

Key words: urban soils; variability; metal pollution; parks; allotments

INTRODUCTION AND BACKGROUND

Concentrations of metallic elements in terrestrial environments have increased significantly as a result of human activities such as emissions from industrial plants and thermal power stations, waste disposal, soil amendments and vehicle traffic/road infrastructures. Low levels of many metals can pose significant health

risks. Metallic pollutants which reach the soil remain present in the pedosphere for many years, even after the removal of pollution sources (Chen *et al.* 1997; Pichtel *et al.* 1997; Imperato *et al.* 2003). To evaluate the significance of often diffuse sources on urban soils, a major pan-European study is under way. A summary of initial findings from the reconnaissance survey are presented in this paper.

In urban areas, soils acquire new functions and play a distinct environmental role. They have aesthetic and recreational functions in parks and gardens, and contribute to the preservation of biodiversity. They directly influence public health: soil material in an urban environment can more easily come into contact with humans and be transferred through the metabolic chain either as resuspended dust or by direct contact (Bullock and Gregory 1991; Ferguson 1999).

While being rarely subject to ordinary agronomic operations, urban soil receives higher than normal loads of contaminants from traffic, industrial activities and waste disposal. The urban soil matrix is often subject to frequent disturbance, through engineering activities and changes in land use, which often end up with exten-

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Authors

Andrew Hursthouse,^{1*} Donna Tognarelli,¹ Peter Tucker,¹ Franco Ajmone Marsan,² Chiara Martini,² Luis Madrid,³ Fernando Madrid³ and Encarnacion Diaz-Barrientos³

1. Chemistry and Chemical Engineering, School of Engineering & Science, University of Paisley, Paisley, PA1 2BE, UK (andrew.hursthouse@paisley.ac.uk)

2. Di.VA.P.R.A.-Chimica Agraria, Università di Torino, Via Leonardo da Vinci, 44 Grugliasco Torino, Italy (franco.ajmonemarsan@unito.it)

3. Instituto de Recursos Naturales y Agrobiología (CSIC), Ave. Reina Merc. Apartado, 1052, 41080 Sevilla, Spain. (madrid@inrase.csic.es)

* corresponding author.

Table 1. Comparison of cities

City	Population	Main pollution sources	Mean annual temperature (°C)	Mean annual precipitation (mm)	Geological substrate	Green areas – extension (ha)
Torino	900 000	Industry/traffic	12.6	750	Alluvial	125
Sevilla	706 000	Traffic	18.2	540	Basaltic/alluvial	273
Glasgow	620 000	Industry/traffic	8.9	991	Alluvial	3870

sive sealing, which alters its relationship with water fluxes. Its substrate can be mixed with other anthropogenic materials that may modify its functioning.

There is a need for a better understanding of the quality and function of urban soils. Some limited work has been undertaken (Effland and Pouyat 1997; Pickett *et al.* 1997, 2001; Jim 1998) and, increasingly, urban geochemistry is identified as a focus of research into the impact of metallic contamination (Paterson *et al.* 1996; Kelly *et al.* 1996; Birke and Rauch 2000; Peltola and Astrom 2003). Whilst these considerable data-sets on chemical contamination add to the description, little regard has been given to soil function as a medium for plant growth, its role in the urban ecosystem and particularly its response to changes in external climatic variables or management conditions. As the debate relating to sustainable urban management and demonstration of appropriate sustainability indicators has evolved, very little consideration has been given to the position of soil and its properties, beyond obvious potential hazard to health, from contaminated sites. Ultimately, the soil system supports and sustains urban development, but we have very little information on its role and significance, and until recently it has been ignored in policy development (Lyons 1997; Pacione 2003; Van Kamp *et al.* 2003).

In an attempt to provide a harmonised approach to urban soil quality, the URBSOIL (<http://urbsoil.paisley.ac.uk>) project was established through EU FP5 Energy, Environment and Sustainable Development –

City of Tomorrow and Cultural Heritage (EVK4-CT-2001-00053). The aim was to focus on urban soils as sources and sinks of pollution, within a common assessment framework, developing decision support systems for sustainable soil management.

As a pilot study to the main URBSOIL project, three cities were selected, which offered a wide range in climate, geology, population, and sources of pollution. The aims of the study were to:

1. survey soil quality and, in a limited number of public parks and gardens as indicated by basic soil properties and using the content of selected metals, to indicate the extent of anthropogenic influence;
2. assess the variability of survey methods and approaches from different cities;
3. evaluate sampling context and site variability in urban soil evaluation;
4. establish general soil properties and description methods for publicly managed land.

This paper reports initial findings from the pilot study, providing a limited soil quality data-set collected from parallel sampling campaigns in three regionally significant historical urban centres: Glasgow, UK, Torino, Italy and Sevilla, Spain. The cities vary in their historical development and regional setting. This can be seen from the wide range of climatic and general conditions, summarised in Table 1.

Table 2. Soil samples collected and sampling methodology used for each city

City	No. of locations	No. of sampling points	Collection method
Sevilla	5 parks and formal gardens, 1 private garden	1–9	Excavation using steel spade to collect from two depths (0–10, 10–20 cm)
Torino	8 parks and formal gardens	12	Excavation using steel spade, 3 composite samples from 4 pits at 2 depths (0–10, 10–20 cm)
Glasgow	4 parks 4 allotments	10	Steel coring device, samples taken 2–3 m from boundary fence, 10 cores collected from within a 1 m ² zone; divided into two depths (0–5, 5–10 cm) Steel coring device, 10 cores collected randomly across site; divided into two depths

MATERIALS AND METHODS

Soil samples were collected from a restricted number of parks, gardens and allotments in the three cities, over a one-year period. Sampling locations were chosen in consultation with the local municipality in each city, to reflect old parkland areas and gardens, which had been subject to continued use over long periods of time. Details of sample collection strategy are provided in Table 2. In two cities (Sevilla and Torino), composite samples were obtained by hand from the locations and, in Glasgow, a standard soil-coring device was used to collect ten replicate samples from a fixed area in four parks and randomly within four allotment gardens (managed by the city authorities).

In all cases, samples were air-dried and gently crushed to pass through a 2 mm sieve, and large stones were removed. The samples were characterised using standard methods for basic soil quality parameters: pH, CEC, organic matter, C/N, P, K, and particle size distribution (Page *et al.* 1982; Gee and Bauder 1986; HMSO 1986; Rowell 1994; Madrid *et al.* 2002), and screened for metal content using an *aqua regia* extract (e.g. Madrid *et al.* 2002). Analysis of metal content was in triplicate, using ICP–OES and flame AAS, with appropriate external standards. The limited amount of sample material collected restricted the analysis of some

properties, particularly in the case of the Glasgow soil samples.

RESULTS AND DISCUSSION

Results for basic soil quality parameters are presented in Table 3, and the soil textural data are shown graphically in Figure 1. Generally, there is quite a variation in the basic soil properties across all data-sets. The soils of Sevilla and Torino are neutral to alkaline, in line with the calcareous nature of the parent material of local soils. Those from Glasgow tend to show lower pH and have slightly more organic matter, as might be expected from the temperate climate experienced in NW Europe. The soil textures for samples from Torino and Glasgow fall into the ‘sand–loamy sand–sandy loam’ region of the USDA classification. Those from Sevilla have a wider textural spread, showing the presence of a significantly higher silt/clay fraction. Where available, data for nutrients are quite variable, reflecting different management conditions, addition (or not) of fertilisers, and related soil properties (e.g. CEC). In all cases, the difference between surface and sub-surface samples was not significant for these parameters. It is difficult to comment on comparisons of these values with ‘expected’ conditions, agricultural standards

Table 3. Summary of basic soil properties

	pH (H ₂ O)	pH (KCl)	CCE* %	Organic C %	Total N %	C/N	P (Olsen) mg/kg	K (exch.) mg/kg	CEC* cmol _(c) /kg	Coarse sand	Fine sand	Silt	Clay %
Sevilla													
mean	7.6		21	1.9	0.19	11	73	318		25	12	37	25
RSD(%)	3		30	62	72	25	165	48		60	67	27	32
max	8.0		35	5.5	0.73	18	550	774		54	34	58	44
min	7.3		3	0.23	0.03	3	1	109		1	1	15	10
n	62		62	62	62	62	62	62		62	62	62	62
Torino													
mean	8.1	7.4	4.8	1.77	0.25	9	20.2	67	11.8	25	42	28	6
CV	4	4	74	49	26	23	128	98	35	14	20	28	30
max	8.6	7.9	14.0	3.8	0.4	13	107	330	19.9	34	55	40	10
min	7.4	6.7	1.1	0.5	0.1	7	1.5	20	3.3	19	28	16	3
n	40	40	40	40	16	16	40	40	40	40	40	40	40
Glasgow													
mean	5.6	5.3	absent	3.2					17	36	37	22	4
RSD(%)	11	15	–	27					27	20	13	25	41
max	7.0	6.7	–	5.6					30	45	44	29	6
min	4.3	4.0	–	1.7					6	24	29	14	1
n	80	32	–	32					43	8	8	8	8

*CCE: Calcium carbonate equivalent; CEC: cation exchange capacity

FIGURE 1. SOIL TEXTURE OF PARK AND GARDEN SAMPLES COLLECTED FROM SEVILLA, TORINO AND GLASGOW

and previous studies, as very little information exists for urban system soil quality (Jim 1998; Pickett *et al.* 2001).

Data for the metal content of soil samples are summarised in Table 4. The values show extremely wide variations for Cu, Zn, Ni, Cr and Pb, with extreme outliers for many elements found for all cities. This is most dramatic in the case of Pb in Glasgow and Sevilla, and, for Torino, relatively high levels of Ni and Cr. The variability is not so high in the case of these elements in samples from Torino, and reflects the contribution of basic/ultrabasic Alpine geology in the region to the soil parent material (Facchinelli *et al.* 2001).

Comparison to what might be expected from an urban soil is supported by numerous examples in the literature. The study by Manta *et al.* (2002) tabulated mean values from a number of published studies of metals in 'urban soils' world-wide. At a superficial level, the mean data from the three cities in the pilot

study fall within a range comparable to levels found elsewhere.

In the cases of Torino and Glasgow, more detailed studies of regional metal levels and variability have been published and are worth commenting on.

For Torino, the range of values (maximum–minimum) observed for Cu, Ni and Cr is close to that for agricultural soils in the region (Facchinelli *et al.* 2001), reflecting the dominance of the natural contribution to Ni and Cr. The situation for Cu is different, and reflects its widespread historical use in agriculture as a pesticide, applied within cities as well as in truly agricultural zones. In the case of Zn and Pb, levels (range, mean) within the urban environment are significantly higher than those found in the wider district, indicating much stronger anthropogenic impacts.

A recent compilation of background levels in Scottish soils (Paterson *et al.* 2003) reviewed soil database information for metal content of mineral soils and a

FIGURE 2. BOX PLOTS OF CONCENTRATIONS OF CU, ZN, CR AND PB IN SURFACE AND SUBSURFACE SOILS FROM: (A) PARKS IN GLASGOW; (B) ALLOTMENTS IN GLASGOW; (C) PARKS IN TORINO; AND (D) PARKS IN SEVILLA

Table 4. Summary of metal content

	Fe %	Mn	Cu	Zn	Ni	Cr	Pb
		mg/kg					
Sevilla							
mean	2.07	491	73	138	22	40	150
RSD (%)	17	24	133	74	26	27	1360
max	3.18	876	698	611	34	64	1080
min	1.33	323	14	38	11	18	14
n	62	62	62	62	62	62	62
Torino							
mean	3.28	947	111	242	193	229	158
RSD (%)	10	12	57	50	24	27	65
max	3.84	1183	293	550	300	356	565
min	2.38	725	40	75	123	126	17
n	39	40	40	40	24	24	40
Glasgow							
mean	3.53		140	364	58	93	971
RSD (%)	19		58	44	33	40	106
max	5.96		484	1004	116	217	7051
min	2.47		52	164	32	40	250
n	62		62	62	62	62	62
Reference values*							
Italy	–	–	120	150	120	150	100
Andalucía, Spain	–	–	150–500	300–1000	80–300	250–400	250–500
UK – ICRCL (gardens)	–	–	130	300	70	600	500
UK – ICRCL (open spaces)	–	–	–	–	–	1000	2000
UK – Minimum CLEA SGV	–	–	–	–	50	130	450

* See Ferguson (1999) and <http://www.clarinet.at/>

specific rural urban transect through the ‘central belt’ region of Scotland in which Glasgow is located. For all elements reported here, the range (maximum–minimum) is significantly higher than both the data for this national survey and the regional transect, suggesting a significant urban signature in the parks and allotments sampled.

A much more detailed analysis of the samples from Sevilla has already been presented (Madrid *et al.* 2002), and tends to confirm observations made about the soils sampled in the cities of Torino and Glasgow. In Sevilla, Cu, Pb and Zn are enhanced in parks and gardens, and there is evidence of a relationship of contamination levels with vehicle movement.

Clearly, direct comparison to results from other studies of absolute concentration levels has relatively limited merit in terms of defining good or bad soil quality, or the impact of urban activities on soil metal content. However, it would appear that a common group of metallic pollutants is a signature of the cumulative impact of general urban processes across urban environments, and is worthy of further investigation.

The range of maximum values would appear to present a challenge to urban managers when compared to ‘guideline’ values for the regulatory regime in each region, given the complexity of the EU dimension to soil contamination (Ferguson 1999). The values at the foot of Table 4, indicate a significant degree of overlap with the results of this study, even in the case of a city where the natural background is high.

Figure 2 (a–d) presents box plots to show the variability of data for surface and sub-surface soil samples from each city. In the case of Glasgow, the samples have been separated into park and allotment data-sets. The variation in metal content within the individual cities is relatively high, with Pb and Zn dominating the patterns in all three cases. The relative scale of variation is different between Glasgow and the other two locations (note axes), but, in all cases, the plots show little difference between the surface and subsurface soils. In the case of Sevilla, the data show no outliers, which are seen for Glasgow and Torino. For the allotment sites in Glasgow, the pattern is similar, with Zn

FIGURE 3. BOX PLOTS TO SHOW WITHIN-SITE VARIABILITY FOR (A) CU, (B) PB AND (C) ZN IN THE FOUR PARK AND FOUR ALLOTMENT SITES IN GLASGOW

and Pb dominating; however, the values show less variation, particularly in the case of Pb.

In Figure 3, the within-site variations for some of the Glasgow soil metal data (Cu, Pb and Zn) are presented for the four park and allotment locations. Plots for Ni and Cr are not included, as the variability is low and little difference was observed between the two different land uses. All data for each metal in surface and sub-surface samples have been pooled. For the park locations, the variation is relatively low, except for Pb in one site and to a lesser extent Zn at another location. Clearly, there is much more variability in the allotment data, which may reflect differences in sampling approach (Table 2). However, this cannot explain the element-to-element variation between sites, and thus emphasises the impact of soil use on metal content.

CONCLUSIONS

This pilot assessment of metal distribution in public parks from three cities in Europe, has highlighted the diverse range of concentrations and the contribution from anthropogenic and natural sources. It has provided a context for future consideration of soil quality in urban environments.

The differences in environmental setting for each of the study locations influence basic soil properties and, consequently, will impact on the relative availability of the metals. From the limited sample-set, the relative variability in metal content between cities seems surprisingly low, when obvious outliers are removed. However, the presence of locations with enhanced levels of, in particular, Pb and Zn, from locations which have remained relatively undisturbed over extended

periods, points to significant potential contributions from diffuse pollution sources over time.

This has obvious implications for the management of the sites and, as discussed widely elsewhere, challenges the strategy for guideline limits/values in managing soil resources. Clearly, some locations would be considered to be in need of more detailed risk assessment/remediation.

The impact of differing land use within the Glasgow sites, as reflected in parkland versus allotment use, again suggests different scales of variability. This would be expected from the contrasting soil turnover/amendment from active agricultural use. It also highlights the potential significance of inter-allotment differences, and the question of different sources of metal.

Clearly, this pilot study has limitations in the description of processes and factors influencing soil metal content. However, it has established a baseline data-set, with the scale of variation in metal content assessed across similar land use types upon which a more detailed investigation has been based. At the time of writing (March 2004), the URBISOIL project is progressing, with a comprehensive assessment of urban soil collected from public open spaces in six cities across the EU. This will include data from approximately 150 locations per city, and information about metal bioavailability, organic contaminants, and large-scale soil processes. The soil quality attributes of the material assessed on the basis of contaminant content and availability, and basic soil properties, will form a harmonised data-set describing the urban soil resource. This will be integrated within a decision-support framework, which will allow exploration of the complex context of sustainable urban management.

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