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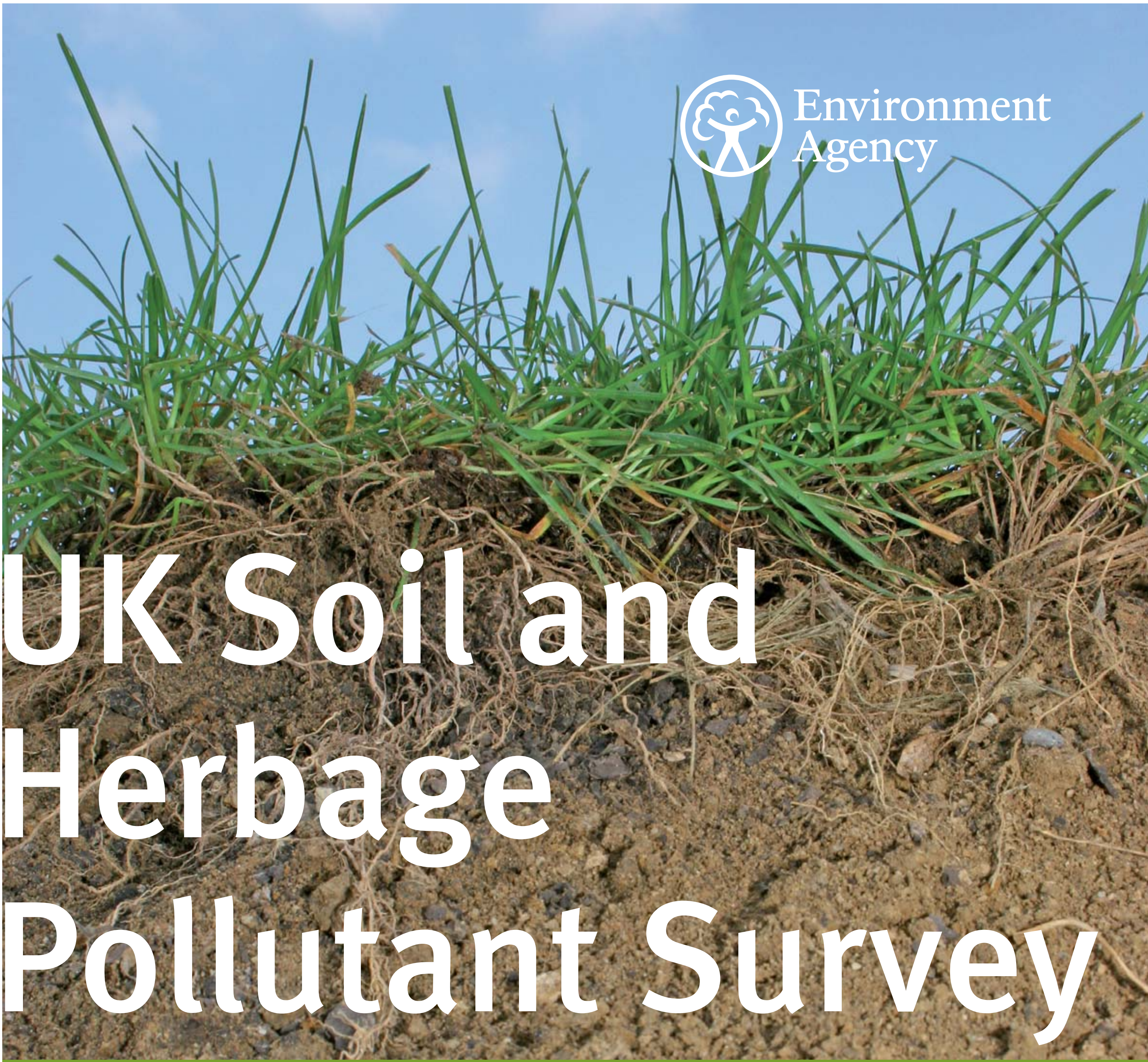

UK Soil and Herbage Pollutant Survey

UKSHS Report No. 7

Environmental concentrations of heavy metals in UK soil and herbage

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- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen
Head of Science

Executive summary

The primary aim of the UK Soil and Herbage Pollutant Survey (UKSHS) project was to establish a baseline for pollutant levels in soil and herbage in the UK. The results are presented in a series of 11 reports and a CD which accompanies UKSHS Report No. 1.

This report, No. 7 in the UKSHS series, discusses the range of concentrations of 13 trace metals and metalloids (arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, platinum, titanium, tin, vanadium and zinc) in soils and herbage from rural, urban and industrial sites across the UK. In all, results for the 13 metals and metalloids are assessed for 122 rural sites, 29 urban sites and 54 industrial sites in England, Scotland, Northern Ireland and Wales.

At the national scale (i.e. England Scotland, Wales and Northern Ireland considered together), the 13 trace elements studied were present in rural soils in concentrations that are within ranges reported in previous surveys of generally uncontaminated UK soils. But there were significant differences between metal concentrations in rural, urban and industrial soils and herbage. For most of the 13 trace elements, mean concentrations in urban and industrial soils were 2–3 times those in rural ‘background’ soils. Mean metal concentrations in herbage broadly mirrored those in soil, suggesting that uptake from the soil is the main pathway for metal contamination of herbage.

At the country scale (i.e. England, Scotland, Wales and Northern Ireland considered separately), there were significant geographical differences in metal/metalloid concentrations in rural and urban soils. The mean concentration of copper in rural soils was significantly higher in Northern Ireland than in the other three countries; and the concentration of chromium in urban soils was higher in Northern Ireland and Scotland. Titanium was significantly higher in Northern Ireland and Scotland than in England and Wales in both rural and urban soils; conversely, arsenic was significantly lower in both rural and urban soils in Northern Ireland and Scotland and lead was lower in rural soils.

No clear patterns of decreasing trace metal concentrations were observed downwind of industrial sites. Semi-quantitative results are presented for 37 less studied elements from soils of industrial sites. Antimony, bismuth, cerium, gadolinium, selenium and molybdenum were found to be present in two or more UK industrial soils at concentrations greater than the generally reported range of concentrations in world soils.

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Note: Appendices 1, 2, 4–7 are available as Excel spreadsheets on the CD that accompanies report UKSHS Report No. 1.

The CD-ROM is available from the Environment Agency publications catalogue (publications.environment-agency.gov.uk) under the following product code:
SCHO0607BMTG-E-C

Glossary of terms

Background Conditions	In the UKSHS, UK background conditions are considered to be those obtained from UKSHS rural sites. Thus, background conditions in England are the range of concentrations representing rural site conditions.
Base position	South-west corner of a northerly orientated 20 m × 20 m sampling area from which GPS readings and triangulation bearings were taken.
Correlation coefficient	An index of the degree of association between continuous variables. It defines the quality of a least squares fitting to the data. The strength of a correlation is indicated by the magnitude of the correlation coefficient. The correlation coefficient can range from 0 to 1 (0 = no correlation and 1 = strong correlation).
Effective stack height	The effective stack height is equal to the physical stack height plus the plume rise.
Industrial	A site dominated by some form of industry.
Null hypothesis	The hypothesis that there is no statistical difference between datasets. This hypothesis is the basis of a statistical test; depending on the outcome of the statistical test, the null hypothesis is either accepted or rejected with a given degree of confidence.
Probability	The chance of a stated outcome of an event occurring.
r^2 values	Coefficient of determination (r^2). This is a measure of the proportion of variability in variable x that is accounted for by the variability in variable y. Where there is a perfect correlation between two variables, a variation in variable x will be exactly matched by a variation in variable y and r will = +1 or –1 (depending on whether it is a positive or negative correlation).
Rural	All other areas not categorised as industrial, urban, semi-urban or semi-rural. Predominantly agricultural land or undeveloped countryside.
Semi-quantitative	This type of analysis identifies which metals are present in a sample and gives an indication of the order of magnitude of the concentration of each metal. This provides a cost-effective means for identifying metals of interest within a sample. These metals can then be targeted using more expensive quantitative analytical techniques.
Semi-rural	Any area within a small town or village. A small town is taken as being 3–20 km^2 in area and a village as being <3 km^2 in area.
Semi-urban	All areas that abut urban centres and/or 25 per cent urbanised/built up. Normally up to 3 km outside the urban core. May also be known as the urban fringe.
Soil–plant concentration factor	Ratio of the concentration of an element in the plant tissue to the concentration of the element in the soil.
Undisturbed site	Unploughed land which has not had chemicals applied (pesticides/herbicides). May include common land, meadows, rough pasture, parkland, fields that are infrequently grazed (if at all0. Avoids wooded areas where possible.
Urban	An area which is ≥90 per cent urbanised/built up. A conurbation may be formed when a large town and city merge. Urban areas include large towns (20–50 km^2 in area) and cities (>50 km^2 in area).

1 Introduction

The UK Soil and Herbage Pollutant Survey (UKSHS) was jointly sponsored by:

- Environment Agency
- Department for Environment, Food and Rural Affairs (Defra)
- National Assembly for Wales
- Food Standards Agency
- Food Standards Agency Scotland
- Scottish Environment Protection Agency (SEPA)
- Environment and Heritage Service (Northern Ireland)
- Scotland and Northern Ireland Forum for Environmental Research (SNIFFER).

A consortium led by the University of Liverpool's School of Biological Sciences was commissioned to undertake the work. The consortium comprised the Environment Agency's National Laboratory Service (NLS), Nottingham Trent University, the University of Stirling and the University of Liverpool (UoL), with additional assistance being provided by Parkman Ltd and the Environmental Advice Centre (EAC) Ltd.

The primary aim of the project was to establish a baseline for pollutant levels in soil and herbage in the UK. The field-based component of the study involved the collection of soil and herbage samples for chemical and radiometric analysis from industrial, rural and urban sites throughout the UK (see UKSHS Report No. 2). A total of 203 sites were visited (see UKSHS Report No. 1). The samples were analysed for a range of organic, inorganic and radionuclide determinands by the NLS and the UoL's radiometric laboratory (see UKSHS Report No. 3 and No. 4). All sample collection and laboratory-based methods used within the UKSHS were accredited by the United Kingdom Accreditation Service (UKAS) to ISO17025.[1]

The methods used in the UKSHS and the data obtained are presented as a series of 11 standalone reports, which can be read individually or as the complete set. This report, Report No. 7 in the series, describes:

- the specific aims and objectives of the survey for heavy metal/metalloid contamination (Section 2);
- the heavy metals/metalloids studied and the method of assessing survey results (Section 3);
- the levels of 13 heavy metals/metalloids in UK soils including their sources, behaviour and fate in soils (Section 4);
- the levels of 13 heavy metals/metalloids in UK herbage (Section 5);

Section 6 provides a summary of the overall findings of the heavy metal/metalloid component of the UKSHS along with recommendations for future studies.

An introduction to the UK Soil and Herbage Survey, together with summary results from all the reports, can be found in UKSHS Report No. 1. A CD enclosed with UKSHS Report No. 1 contains all the data for rural, urban and industrial sites together with a suite of macros to enable the user to interrogate the datasets.

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[1] The University of Liverpool is a UKAS-accredited testing laboratory (No. 2049). Opinions and interpretations expressed herein are outside the scope of accreditation.

2 Aims and objectives

The overall aims and objectives of the UKSHS are detailed in the introductory report (UKSHS Report No. 1). Each report in the series addresses one or more of these aims and objectives. This report addresses the following specific aims:

- to create a dataset that provides a national overview of heavy metal and arsenic concentrations in soil and herbage as a baseline against which future national surveys can be compared;

- to provide information about the current environmental concentrations of heavy metals/arsenic obtained using the best techniques;

- to compare these concentrations with the results of previous studies in order to establish possible trends;

- to identify gaps in knowledge and opportunities for further work.

3 Heavy metals and metalloids studied

Thirteen metals and metalloids were determined in both soil and herbage samples. These are discussed under three classification headings (Table 3.1).

Table 3.1 – Heavy metals and metalloids studied in the UKSHS

Classification	Element
Transition metals	Cadmium (Cd) Chromium (Cr) Copper (Cu) Manganese (Mn) Mercury (Hg) Nickel (Ni) Platinum (Pt) Titanium (Ti) Vanadium (V) Zinc (Zn)
Other metals	Lead (Pb) Tin (Sn)
Metalloids	Arsenic (As)

The data for heavy metals and arsenic collected in the UKSHS are compared with results from other studies at appropriate points throughout the report.

The ‘raw’ UKSHS data are used when interpreting the data on heavy metals and arsenic. No attempt was made to remove ‘outliers’ from the dataset because close inspection of the data revealed that the only values statistically calculated as outliers came from just a few sites. In one instance, all the sub-samples at a single site were calculated as statistical outliers. Since these data could represent real hotspots of metal contamination, no statistical reduction of data was attempted and the full dataset is used throughout. All original, raw data are presented in this report and its appendices.

It is important to be aware of the appropriate use of these data. The information is most powerful at the national scale where the number of samples is sufficient to provide statistical robustness. At the national scale, stratifying data to rural, urban or industrial sites still provides statistical robustness (n = 366, n = 87, n = 216 respectively). But caution is necessary when interpreting individual site data as, in general, the statistics will not be robust (n = 3 or 4).

For industrial sites, samples were normally collected at four locations:

- a nominal ‘upwind’ site;
- three sites at increasing ‘downwind’ distances corresponding to an effective stack height (He) of 5, 10 and 15.

Because of the statistical limitations mentioned above, data from individual sites are not discussed.

The data are presented in two main ways.

- Mean values of the aggregated data from urban and rural soils and herbage are compared with the appropriate mean value for the aggregated rural dataset. Differences at the $p < 0.05$ and $p < 0.01$ level are indicated by one or two asterisks respectively.

- Data aggregated at the country scale (i.e. England, Wales, Scotland or Northern Ireland) are compared in tables in the main text. Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Where appropriate, data from UKSHS are compared with data from earlier surveys such as McGrath and Loveland (1992), Black *et al.* (2002) and Ashmore *et al.* (2000). In many cases, the range of concentrations observed in the UKSHS is narrower than in these surveys. This partly reflects differences in geographical coverage. However, it is also because contaminated sites such as mining, industrial and waste sites were included in the general dataset of McGrath and Loveland (1992) but are considered separately in the UKSHS.

Very little variation in Pt concentrations was found in soils or vegetation throughout the entire UKSHS. This lack of pattern may be due to the detection limit of the analytical technique for Pt (final recording concentration of 0.02 mg/kg Pt in both soils and vegetation). For this reason, no detailed interpretation of Pt concentration patterns is made for either soil or herbage samples in this report.

Full results for rural, urban and industrial sites (Appendices 1, 2, 4, 5, 6 and 7) are available as Microsoft Excel® spreadsheets on the CD that accompanies UKSHS Report No. 1.

4 Heavy metal and metalloid concentrations in UK soils

4.1 Soils from rural locations

The full dataset for concentrations of the selected 13 heavy metals and metalloids (As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Pt, Sn, Ti, V and Zn) determined in rural soils collected from sites in England, Northern Ireland, Scotland and Wales (n = 366) is presented in Appendix 1 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of soil.

Histograms (Figure 4.1) with minimum and maximum ranges of concentrations (added as ‘bars’) are provided for each element for:

- the entire UK dataset;
- England, Northern Ireland, Scotland and Wales individually.

Descriptive statistics for the full dataset and for each of the regions (England, Northern Ireland, Scotland and Wales) are presented in this section of the report in separate tables for each element studied.

4.1.1 Transition metals

Cadmium (Cd)

Cd is an element that occurs naturally in rocks, soils, plants and animals. It occurs especially in shales and clays, and sulphide mineralisation. Anthropogenic sources of Cd include:

- non-ferrous metallurgical smelting;
- pyrometallurgical industries;
- phosphate fertilisers;
- sewage sludges.

The behaviour of Cd in the environment and related health aspects was reviewed by Kabata-Pendias and Pendias (1999) and by Stoeppler (1991).

The most common form of cadmium in soils is ionic Cd^{2+}, which is adsorbed on naturally occurring iron and manganese oxides in soil and can also be held by cation exchange on silicate clay minerals.

Cd is relatively mobile in temperate soils. Its retention and mobility depend on pH such that retention declines and mobility and bio-availability increase under acidic conditions; Cd is most mobile in acidic soils within the range pH 4.5 to 5.5. Leaching in drainage waters is not commonly an environmental risk since, above pH 7.5, Cd sorbed in soils is not easily mobile (Kabata-Pendias 2000). The carbonate concentration in the soil solution is a principal factor in Cd immobilisation through precipitation (Isenbeck *et al.* 1987).

Summary statistics are provided for each of the four countries in Table 4.1 and illustrated in Figure 4.1a.

Table 4.1 – Cd concentrations in rural soils of different countries in the UKSHS (mg/kg)

	n	Range	Mean	Median	SD
UK	366	0.10–1.80	0.39	0.29	0.32
England	183	0.10–1.78	0.43a	0.31	0.35
N. Ireland	30	0.18–0.68	0.38a	0.35	0.15
Scotland	120	0.10–1.80	0.34b	0.23	0.32
Wales	33	0.15–0.88	0.39b	0.30	0.19

SD = standard deviation

The range of concentrations of Cd in UK rural soils, considered as UK 'background' conditions in the UKSHS, can be compared with concentrations reported generally for UK soils (Table 4.2).

Table 4.2 – Reported concentrations of Cd in UK soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	0.10–1.8	0.39	0.29
Alloway *et al.* (1998)[1]	0.114–0.744	0.35	0.34
Archer and Hodgson (1987)	<1.0–10.5	0.6	0.5
Ashmore *et al.* (2000)[2]	0.3–51.6	–	1.0
Black *et al.* (2002)	0–11.2	0.49	0.3
Fergusson (1990)	0.01–2	–	–
McGrath and Loveland (1992)	<0.2–40.9	0.80	0.7

[1] Agricultural soils (0–20 cm) at 34 sites remote from obvious sources of pollution
[2] Upland soils in England and Wales

Cd concentrations in rural soil were significantly lower in Scotland than in England. The geographical difference across the UK probably indicates higher prevalence and closer proximity, even in rural locations, to activities generating Cd contamination (e.g. lead and zinc mining or associated smelting) rather than the more widespread use of phosphate fertilisers or use of sewage sludge on land.

Reported Cd concentrations in world soils are given in Table 4.3. When compared with European Soil Bureau (2000) data for France and Germany (Appendix 10), Cd concentrations found in the UKSHS are well within the ranges found in these two countries and the medians are very similar.

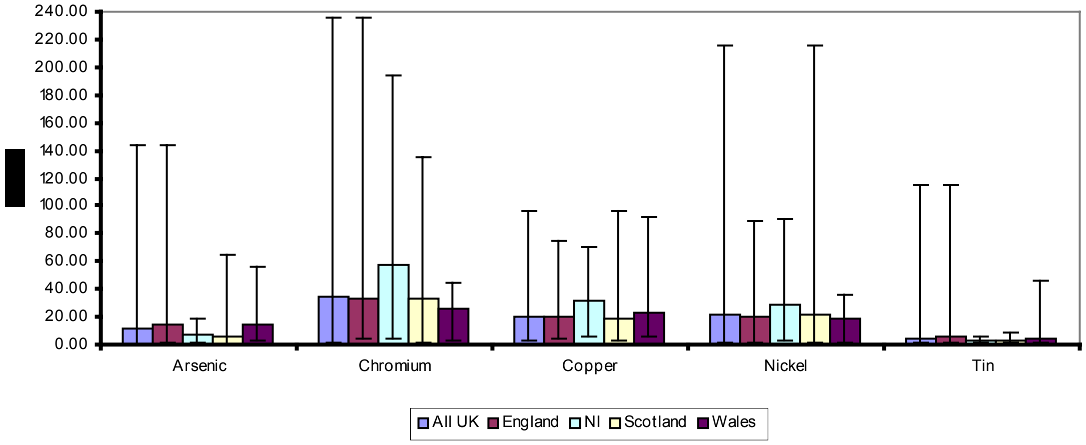
Table 4.3 – Reported concentrations of Cd in world soils (mg/kg)

Reference	Range	Mean	Median
Govindaraju (1994)	0.06–4.3	–	–
Holmgren *et al.* (1993)[1]	<0.01–2.0	0.27	0.2
Kabata-Pendias (2000)[2]	0.06–1.1	–	–
Motuzova *et al* (1999)[3]	0.2–1.14	–	–
Reimann *et al.* (2003)[4]	<0.005–1.1	0.17	0.13

[1] 3,045 agricultural soils from unpolluted sites in the USA
[2] World soils; also quotes concentrations from the literature of 0.01–2.7 mg/kg Cd
[3] Soils from the remote Sichote-Alin region of Russia
[4] *Aqua regia* extractable Cd in 750 soils (0–25 cm) from the Baltic Soil Survey

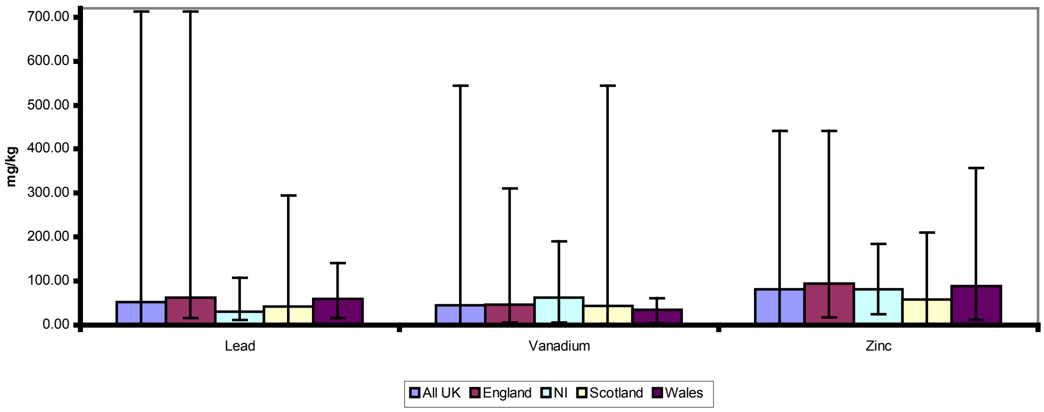
(a)

Rural Soil As Cr Cu Ni & Sn Concentrations



(b)

Rural Soil Pb, V & Zn Concentrations



(c)

Rural Soil Cd Hg & Pt Concentrations

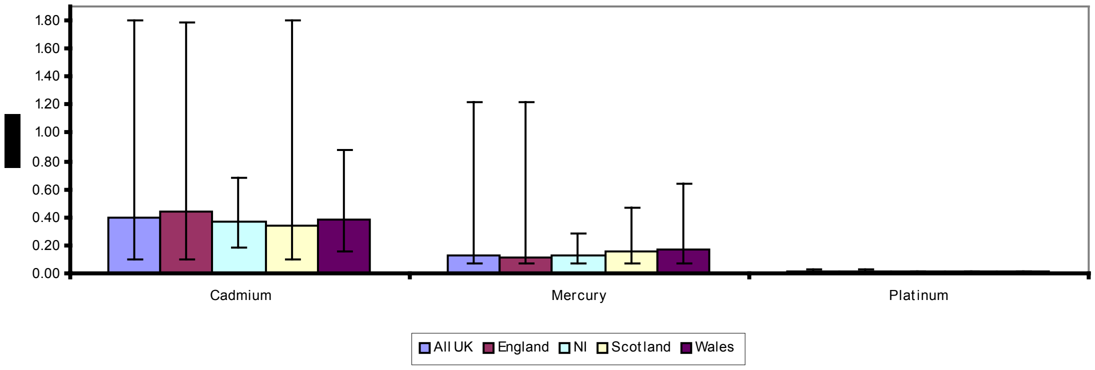


Figure 4.1 – Means and ranges of metal/metalloid concentrations in rural soils

Chromium (Cr)

Cr is an element that occurs naturally in rocks, soil, plants and animals. Cr is a micronutrient for animals. The most common forms of Cr are Cr(III), which occurs naturally, and Cr(VI) which is generally produced by fuel combustion, waste incineration and industrial processes such as alloy steel manufacture. Both ionic forms of Cr are held strongly in soil by cation exchange, and are more mobile and more bio-available under acidic conditions. Cr(VI) is recognised as being more toxic to humans but can be reduced to the less toxic Cr(III) in waterlogged soils and sediments. Plant uptake and transfer into the food chain is limited, even under acid soil conditions.

Summary statistics are provided for each of the four countries in Table 4.4 and illustrated in Figure 4.1a. Table 4.5 compares UKSHS data with data from earlier surveys.

Table 4.4 – Concentrations of Cr in rural soils of different countries in the UKSHS (mg/kg)#

Chromium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	1.14–236	34.41	29.20	29.77
England	183	3.89–236	33.44[a]	29.50	26.29
N. Ireland	30	3.78–194	57.43[a]	39.15	52.86
Scotland	120	1.14–135	32.59[b]	26.15	27.84
Wales	33	3.09–44.7	25.52[b]	26.80	12.96

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Table 4.5 – Reported concentrations of Cr in UK soils (mg/kg)#

Reference	**Range**	**Mean**	**Median**
UKSHS	1.14–236	34.41	29.2
Alloway *et al.* (1998)[1]	9.6–60	32.6	30.7
Archer and Hodgson (1987)	4.0–160[d]	42.4	54.0
Berrow and Reaves (1984)[2]	7.8–640[f]	71	–
Berrow and Reaves (1984)[3]	0.5–10,000	150	–
Black *et al*. (2002)	0–267[c]	28.5	26.5
Braithwaite (1995)	5–1,500	50	–
McGrath and Loveland (1992)	0.2–838[b]	41.2	39.3
McGrath (1995)	0.3–837	34	–

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

[1] Topsoils (0–20 cm) at 34 sites remote from obvious sources of pollution

[2] Mineral topsoils

[3] All soils

Table 4.6 – Reported concentrations of Cr in world soils (mg/kg)

Reference	**Range**	**Mean**
Bini *et al.* (1988)[1]	20–307	95
Kabata-Pendias and Wiacek (1985)[2]	4–68	20
Shacklette and Boerngen (1984)[3]	7–1,500	50

[1] Surface soils of Italy

[2] Contaminated surface soils in Poland

[3] Surface soils in the USA

Across the UK, the widest ranges and maximum Cr concentrations in rural soils were found in England and Northern Ireland (Table 4.4). Mean Cr concentrations Northern Ireland were significantly higher than in England, Wales and Scotland.

It is highly likely that the high Cr values in Northern Ireland are related to its geology/geochemistry with outcrops of mafic (basic igneous) rocks. The range of Cr concentrations in Scottish soils was lower than that reported for mineral topsoils by Berrow and Reaves (1984) and much lower than that reported for all soils by the same authors. When compared with European Soil Bureau (2000) data for Germany (Appendix 10), the median Cr values for the four UKSHS countries are significantly higher, especially in Northern Ireland.

Comparative data on Cr concentrations in world soils are given in Table 4.6.

Copper (Cu)

Cu occurs naturally in rocks, soils, plants and animals. It is an essential trace element (micronutrient) for both plants and animals, and it can also occur in sulphide mineralisation. Copper is present in fallout from volcanic activity and also enters the environment:

- in atmospheric deposition from mining, metal smelting and metal processing industries;
- when waste is incinerated;
- when wood products and fossil fuels are burnt.

Copper is also present in flyash from coal-burning power stations.

Cu forms complexes with humic and fulvic acids in soils. These organo-copper complexes are more mobile under acidic conditions and there is some potential for leaching of Cu in acidic, organic soils. In neutral to alkaline soils, Cu complexes separate out and become adsorbed onto the surfaces of clay minerals where they are strongly held. Under these conditions, Cu is one the least mobile trace metals in soil. Reeves and Berrow (1984) considered that total Cu concentrations in soil of <5 mg/kg could result in crops suffering from copper deficiency.

Summary statistics are provided for each of the four countries in Table 4.7 and illustrated in Figure 4.1a. Table 4.8 compares UKSHS data with data from other surveys.

Table 4.7 – Concentrations of Cu in rural soils of different countries in the UKSHS (mg/kg)#

Copper	*n*	Range	Mean	Median	SD
UK	366	2.27–96.7	20.64	17.25	15.29
England	183	4.80–75.2	19.79^{b}	17.40	12.69
N. Ireland	30	5.89–70.8	31.64^{a}	31.10	14.31
Scotland	120	2.27–96.7	18.48^{c}	13.55	17.66
Wales	33	6.30–91.3	23.23^{b}	20.30	16.20

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

Table 4.8 – Reported concentrations of Cu in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	2.27–96.7	20.64	17.25
Abbott *et al*. (1997)	2–19	8.7	–
Alloway *et al.* (1998)[1]	3.2–55.6	17.4	15.3
Archer and Hodgson (1987)	1.8–215	19.0	18.4
Ashmore *et al*. (2000)[2]	6–1,790	–	20.5
Baker and Senft (1995)	2–150	–	–
Black *et al*. (2002)	0.3–448	18.1	13.6
Braithwaite (1995)	2–250	–	–
Holmgren *et al.* (1993)[3]	0.6–492	29.6	18.5
McGrath and Loveland (1992)	1.2–1,508	23.1	18.1
Reiman *et al.* (2003)[4]			

[1] *Aqua regia* extractable Cu in 34 rural/agricultural soils in England and Wales from sites remote from obvious sources of pollution
[2] Upland soils in England and Wales
[3] 3,045 agricultural soils in the USA
[4] 750 top soils (0–25 cm) analysed in the Baltic Soil Survey

The highest Cu maximum concentrations and the widest Cu concentration ranges were found in rural soils in Scotland and Wales (Table 4.7). Mean Cu concentrations were significantly higher in Northern Ireland than in England, Wales and Scotland.

Cu accumulation in topsoils is generally associated with fallout from mining and associated smelting or, more recently, from the application of sewage sludges to land. It is possible that mining over several centuries has contributed to the higher maximum values found in Scotland and Wales. It may also be worth noting that copper used to be used extensively as a fungicide on potatoes, etc. and spray drift could have resulted in soil contamination. Copper has also been used in relatively large quantities in some livestock feeds. Land receiving livestock manures from animals fed on Cu-fortified diets would be expected to have elevated Cu contents.

Although the maximum Cu value reported for soils in France in the European Soil Bureau (2000) survey (9 mg/kg) is much higher than the maxima in the four UKSHS countries, the median concentrations in the UKSHS are all higher than in either France or Germany, with the exception of Wales.

Manganese (Mn)

Mn occurs naturally in rocks, soils, sediments, plants and animals, and is an essential trace element (micronutrient) for both animals and plants. It is generally present in soils in higher concentrations than other trace elements apart from iron.

Manganese can enter the environment in atmospheric deposition from the exhaust emissions of vehicles running on lead replacement petrol. It can also be released from industrial processes such as the manufacture of engineering steels and electrical storage batteries.

Manganese oxides vary in their solubility in aerated soils. Ionic forms of Mn present in soil are the oxidised Mn^{4+} (manganic) and the reduced Mn^{2+} (manganous) forms. Reduction of manganese in anaerobic and waterlogged soils causes it to be mobilised, leading to potential leaching in drainage waters. Reduction also increases bio-availability as Mn^{2+} is the main form of Mn used by plants. During oxidation processes, MnO_2 crystallises and forms films around soil particles. These can be important sites of ionic adsorption in soil. Under acidic soil conditions, Mn retention in soil is likely to decline as soil cation exchange capacity declines.

Summary statistics are provided for each of the four countries in Table 4.9. Table 4.10 compares UKSHS data with data from earlier surveys.

Table 4.9 – Concentrations of Mn in rural soils of different countries in the UKSHS (mg/kg)#

Manganese	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	10–12,200	612	420	938
England	183	27.7–2,890	614^{a}	450	521
N. Ireland	30	76.8–1,200	433^{c}	308	319
Scotland	120	10–12,200	656b^{c}	395	1,484
Wales	33	44.4–1,670	598b^{ac}	591	410

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

Table 4.10 – Reported concentrations of Mn in UK soils (mg/kg)

Reference	**Range**	**Mean**	**Median**
UKSHS	10–12,200	612	420
Abbott *et al*. (1997)	300–1,800	–	–
McGrath and Loveland (1992)	3.0–42,600	761	577
Smith and Paterson (1995)	50–11,500	–	–

The mean Mn concentration in rural soils was somewhat lower in Northern Ireland than in England, Scotland and Wales. Individual high concentrations probably reflect the local geology. Basic igneous rocks and materials (e.g. glacial tills derived from serpentine, andesites, olivine gabbro and certain granites) are all high in manganese (Smith and Paterson 1995). Elsewhere in the UK, Mn concentrations in soil generally reflected much lower Mn concentrations in the parent materials.

Kabata-Pendias (2000) reported Mn concentrations in various world soils to range from 12–8,423 mg/kg Mn, with means of between 279 and 1,055 mg/kg.

Mercury (Hg)

Hg is a naturally occurring element in various rock minerals. It can also enter the environment in atmospheric deposition from volcanic activity, combustion of fossil fuels and from ore smelting. It is released from industrial processes – particularly the Hg cell chlor-alkali process for the production of chlorine and caustic soda – and also from some biochemical processes. Other possible sources of Hg in soils include the application of sewage sludges to land and the use of Hg fungicides. Long-range atmospheric transport of Hg from anthropogenic sources is an important source of Hg to surface soils, particularly to organic soils (e.g. Hakanson *et al.* 1990, Steinnes and Andersson 1991).

Hg is found in three principal forms in soils:

- ionic
- organic (methylated, etc.)
- complexed with humic soil organic matter.

In well-aerated soils, Hg has a strong ability to form ionic complexes and is rarely found in free ionic form under natural conditions. In acid soil conditions, Hg is likely to be relatively strongly bound to organic compounds. Above pH 7, the most common stable form is hydrated HgO (c.f. Steinnes 1995).

Hg binds strongly to sulphide ions and, under waterlogged and reducing conditions, it forms precipitated sulphur compounds that are stable. The accumulation of Hg in soil is controlled mainly by organic complex formation and by precipitation (Kabata-Pendias, 2000). Only a very minute fraction of Hg^{2+} occurs in the soil solution, the major fraction being either bound in soil minerals, or adsorbed on both organic and inorganic solid surfaces.

Soil bacteria and fungi facilitate the formation of methylmercury and its derivatives. Methylmercury forms slightly mobile complexes with humic and fulvic compounds in soil organic matter. Leaching of Hg in drainage waters is a possible environmental risk in acidic soils with high organic matter content.

Summary statistics provided for each of the four countries in Table 4.11 and illustrated in Figure 4.1c.

Table 4.11 – Concentrations of Hg in rural soils of different countries in the UKSHS (mg/kg)#

Mercury	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	0.07–1.22	0.13	0.10	0.10
England	183	0.07–1.22	0.11^{a}	0.09	0.10
N. Ireland	30	0.07–0.28	0.13^{a}	0.11	0.06
Scotland	120	0.07–0.48	0.15^{a}	0.12	0.09
Wales	33	0.07–0.64	0.17^{a}	0.11	0.13

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Mean Hg concentrations in rural soils in Wales were somewhat higher than those in England, with Northern Ireland and Scotland being intermediate. The highest Hg maximum concentrations and the largest Hg concentration ranges were found in rural soils in England (Table 4.11).

There are no previous surveys reporting Hg concentrations in soils throughout the whole of the UK. Table 4.12 compares previously reported ranges of Hg concentrations in agricultural soils with the data obtained from rural soil samples in the UKSHS.

Table 4.12 – Reported concentrations of Hg in UK soils (mg/kg)

Reference	**Range**	**Mean**	**Median**
UKSHS	0.07–1.22	0.13	0.10
Abbott *et al.* (1997)	0.1–0.2	–	–
Alloway *et al.* (1998)[1]	0.073–0.229	0.11	0.099
Archer and Hodgson (1987)	0.01–2.12	0.09	0.09
Fergusson (1990)[2]	0.008–0.19	–	–
Fergusson (1990)[3]	0.01–1.71	–	–

[1] *Aqua regia* extractable Hg in soils (0–20 cm) at 34 sites in England and Wales remote from obvious sources of pollution
[2] English soils
[3] Scottish soils

Reported concentrations of mercury in world soils are given in Table 4.13. The median value for Hg in German soils in the European Soil Bureau (2000) data (Appendix10) is similar to the values for the four UKSHS countries but the median Hg content in French soils is much lower.

Table 4.13 – Reported concentrations of mercury in world soils (mg/kg)

Reference	Range	Mean
Haidouti *et al.* (1985)[1]	0.033–0.101	–
Lis and Pasieczna (1995)[2]	0.05–1.4	0.09
Malgin and Puzanov (1995)[3]	0.01–0.29	0.08

[1] Greek soils
[2] Peats in Poland
[3] Russian soils (Asia)

Nickel (Ni)

Ni occurs naturally in rocks, soils, plants and animals, and was recently proved to be essential for plants. It is released in fallout from volcanic activity and also enters the environment in atmospheric deposition from metal processing industries and from the burning of fuel oils. High concentrations of Ni (100–7,000 mg/kg) are found in soils derived from serpentine.

Ni in soils is commonly associated with manganese and iron oxides, or in combination with sulphur, or as a hydrated silicate. Ni is also present in soluble chelates.

Where the soil is acidic and reducing, nickel sulphide deposits are likely to control the concentration of Ni in the soil solution. Ni^{2+} is exchanged in soil on cation exchange sites of clay minerals and organic matter and becomes adsorbed on naturally occurring iron and manganese oxides in soil. Ni mobility is thus increased under acidic soil conditions in temperate soils when cation exchange is lower; under these conditions, leaching in drainage waters could be an environmental risk.

Summary statistics are provided for each of the four countries in Table 4.14 and illustrated in Figure 4.1a.

Table 4.14 – Concentrations of Ni in rural soils of different countries in the UKSHS (mg/kg)#

Nickel	*n*	Range	Mean	Median	SD
UK	366	1.16–216	21.1	15.8	24.1
England	183	2.13–88.9	19.5[a]	16.4	11.9
N. Ireland	30	3.33–91.1	28.8[a]	21.0	25.2
Scotland	120	1.16–216	22.2[b]	11.0	36.8
Wales	33	1.96–36.3	18.3[ab]	17.4	11.3

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Mean Ni concentrations were higher in Northern Ireland than in England and Wales. The highest Ni maximum concentrations and the widest Ni concentration ranges were found in rural soils in Scotland (Table 4.14). Just two sites contributed high Ni concentrations to the Scottish dataset, increasing the mean and standard deviation accordingly. These higher rural soil concentrations are likely to reflect the local geology. Ultramafic igneous rocks and materials derived from these rocks are all high in Ni (McGrath 1995). Just one site in England had Ni concentrations that are significantly higher than the bulk of English data. Elsewhere in the UK, soil Ni concentrations generally reflected lower Ni concentrations in parent materials.

Table 4.15 compares UKSHS data with data from other surveys.

Table 4.15 – Reported concentrations of Ni in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	1.16–216	21.1	15.8
Abbott *et al*. (1997)	5.3–32	14.2	–
Alloway *et al*. (1998)[1]	0.8–58.5	21.6	17.6
Archer and Hodgson (1987)	2.0–98	22.6	23.7
Berrow and Reaves (1984)	4.8–200	31	–
Black *et al*. (2002)	0–1,890	23.7	16.3
Kabata-Pendias and Wiacek (1985)[2]	1.3–68	9	–
Kabata-Pendias (2000)[3]	0.2–450	–	–
Kabata-Pendias (2000)[4]	<5–150	–	–
McGrath and Loveland (1992)	0.8–440	24.5	22.6
McGrath (1995)	0.1–5,000	–	–
Reimann *et al*. (2003)[5]	<2–619	10	8

[1] *Aqua regia* extractable Ni in soils at 34 sites in England and Wales remote from obvious sources of pollution
[2] Surface soils in Poland
[3] Broad range for world soils
[4] Soils of the USA
[5] 750 topsoils (0–25 cm) in the Baltic Soil Survey

The median Ni contents in the four UKSHS countries are similar to those found in the European Soil Bureau (2000) data (Appendix 10) for France and Germany.

The grand mean Ni concentration for world soils has been calculated to be 22 mg/kg and the mean for soils in the USA has been reported to be 19 mg/kg (Shacklette and Boerngen 1984).

Platinum (Pt)

Pt has been used in vehicle catalytic converters since the late 1970s. Under EU Directive 91/441/EEC, such use has been mandatory in the UK since 1993.

It is now apparent that modern vehicles release Pt particulates into the atmosphere and that these can accumulate in roadside soils. Pt is relatively insoluble in soil (<10 per cent of Pt dust becomes soluble in soil), its solubility increasing in soils that are high in organic matter (Lustig *et al*. (1996). How Pt is transformed or fixed in soil is not yet known in detail, but high chloride concentrations and highly acidic soil conditions can increase mobility and bioavailability.

Summary statistics are provided for each of the four countries in Table 4.16 and illustrated in Figure 4.1c.

Table 4.16 – Concentrations of Pt in rural soils of different countries in the UKSHS (mg/kg)

Platinum	*n*	Range	Mean	Median	SD
UK	366	0.02–0.02	0.02	0.02	0.00
England	183	0.02–0.09	0.02	0.02	0.00
N. Ireland	30	0.02–0.02	0.02	0.02	0.00
Scotland	120	0.02–0.02	0.02	0.02	0.00
Wales	33	0.02–0.02	0.02	0.02	0.00

These data reflect the limit of detection (LOD) for platinum (0.02 mg/kg) and no statistical analyses were performed on the data.

There are few data worldwide on soil Pt that could be used as a benchmark in interpretation of the UKSHS results. However, the range of concentrations of Pt in UK rural soils, considered as UK ‘background’ conditions in the UKSHS, was relatively low compared with concentrations reported previously for urban roadside soils and road dusts in the UK, Germany and the USA (Table 4.17). However, the majority of studies – including those in the UK (Farago *et al*. 1998, Higney *et al*. 2002) – involved analysis of road dust rather than of roadside soils. This alone could account for the higher Pt concentrations found compared with UKSHS rural soil samples.

Table 4.17 – Reported concentrations of Pt in UK and world soils (mg/kg)

Reference	Country	Range	Mean	Median
UKSHS	UK	0.02–0.02	0.02	0.02
Alloway *et al.* (1998)[1]	England and Wales	0.02–4.22	0.91	0.48
Ely *et al.* (2001)	Indiana, USA (road side soil)	0.064–0.073	–	–
Farago *et al* (1998)	UK (road dust)	0.011–0.024	–	–
Higney *et al* (2002)	Scotland (road dust)	0.013–0.335	–	–
National Academy of Sciences (1977)	USA	0.06–0.09	0.08	–
Ravindra *et al.* (2004)[2]	England	0.05–4.45 x 10^{-3}	–	–
Schafer *et al* (1999)	Germany	0.146–0.157	–	–

[1] *Aqua regia* extractable Pt in soils (0–20 cm) at 34 sites remote from obvious sources of pollution

[2] Quotes various values from Farago *et al.* (1986-1992) for soils near highways; various other Pt concentrations in soils (usually near roads) are given.

Govindaraju (1994) reported concentrations of 0.05 mg/kg and 0.15 mg/kg of Pt in two samples of reference soils. A recent study in Scotland (Higney *et al*. 2002) indicated significantly elevated levels of Pt (0.013–0.335 mg/kg) in road dust samples from a dual carriageway and a motorway near East Kilbride compared with concentrations in surface soils in the area (<0.001 mg/kg). Farago *et al*. (1998) also reported elevated Pt concentrations in urban road dust (0.011–0.024 mg/kg). Although Pt concentration ranges of 0.06–0.09 mg/kg have been reported for soils on heavily used urban roadsides in the USA, these concentrations were described as representing high vehicle usage (5,000 vehicles per day) over a 10-year period (NAS 1977) and are hence atypical of general rural conditions. Ely *et al*. (2001), however, warned that there was good evidence to show that Pt contamination from traffic could be transported >50 metres from the roadside.

Titanium (Ti)

Ti enters the environment through natural weathering of minerals such as rutile (TiO_2) and various mixed oxides, titanates and silicate-based minerals. Ti can also be present in atmospheric pollution from industrial processes involving titanium tetrachloride.

Ti minerals are considered to be the most stable minerals in the soil environment. Any industrial releases of titanium tetrachloride react with moisture to form hydrated titanium dioxide. Ti compounds in soil tend to be stable, poorly soluble and they remain in soil for long periods of time. Thus, the potential for leaching or water transport of Ti compounds, and hence environmental risk, is very low.

The main reason for including Ti in the suite of analyses for the UKSHS was to be able to investigate possible soil contamination of herbage (see Section 5.5). However, it has been reported that perhaps Ti is not always a good indicator of soil contamination of herbage; Mitchell (1964) found that some native plant species in Scotland appeared to accumulate considerable amounts of Ti, possibly as soluble organic complexes. Mitchell commented that this high uptake of chelated trace elements may explain the relatively high plant uptake of such elements as Ti and V from certain soils in which suitable chelating agents may be present. Kabata-Pendias (2000) stated that there is some evidence that Ti may have a beneficial impact on carbohydrate metabolism in plants, but it has not yet been proved to be an essential trace element. This could imply that some Ti is normally taken up by plants and this should be borne in mind when considering the use of Ti as an indicator of soil contamination.

Summary statistics are provided for each of the four countries in Table 4.18.

Table 4.18 – Concentrations of Ti in rural soils of different countries in the UKSHS (mg/kg)#

Titanium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	12.7–3,280	369	178	519
England	183	16.9–2,090	201[b]	160	240
N. Ireland	30	26.8–3,280	699[a]	450	878
Scotland	120	26.7–2,900	609[a]	366	633
Wales	33	12.7–510	125[c]	56.3	136

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Data on Ti concentrations in UK and world soils are given in Table 4.19. They show that Ti is an abundant element in soil with concentrations of up to about 3,600 mg/kg for uncontaminated soils.

Kabata-Pendias (2000) quotes a general range of 0.1–0.9 per cent (1,000–9,000 mg/kg Ti) but gives a wider range of 0.02–2.4 per cent (200–24,000 mg/kg) in a table. The lower concentrations in both these ranges are very much higher than those found in either the UKSHS or by Alloway *et al.* (1998) or Reimann *et al.* (2003). This is probably due to incomplete extraction from the soil in aqua regia. Only a digestion in a mixture of hot $HClO_4$, HNO_3 and HF acids can release the total Ti content (Alloway B J, personal communication).

The range of concentrations of Ti in UK rural soils, considered as UK 'background' conditions in the UKSHS, includes lower values similar to those which have been reported previously by Alloway *et al.* (1998).

Table 4.19 – Reported concentrations of Ti in UK and world soils (mg/kg)

Reference	**Country**	**Range**	**Mean**	**Median**
UKSHS	UK	12.7–3,280	369	178
Alloway *et al.* (1998)[1]	England and Wales	12.1–487.4	149	144
Healy (1968)	New Zealand	1,000–3,000	–	–
Jones and Doner (1997)[2]	California, USA	5,900–110,000	–	–
Kabata-Pendias (2000)	World soils	1,000–9,000	3,500	–
McBride (1994)	US soils	1,800–3,600		
Mayland *et al*. (1975)	Idaho, USA	2,100–2,400	–	–
Mayland and Sneva (1983)	Oregon, USA	–	4,785	–
Reimann *et al.* (2003)[3]	Baltic Survey	10.4–2,110	339	166
Shacklette and Boerngen (1984)	USA	500–10,000	3,000	–

[1] Aqua regia extractable Ti in soils (0–20 cm) at 34 sites remote from obvious sources of pollution
[2] Contaminated soils
[3] Aqua regia extractable Ti in 750 topsoils (0–25 cm) in the Baltic Soil Survey

Mean concentrations in Northern Ireland and Scotland were significantly higher than those in England and Wales. The reasons are unclear, with several sites showing Ti concentrations higher than in the rest of the UK. Just one sample from one site in Scotland had a very high Ti concentration; otherwise the range of Scottish Ti concentrations would be 2–120 mg/kg. High Ti concentrations in soil may be a result of local mineralogy or possibly be due to proximity to industrial activity such as paint or pigment manufacture.

Vanadium (V)

V is found naturally in the Earth's crust in rocks, some iron ores and in petroleum deposits. It also enters the environment in atmospheric pollution from alloy manufacture, the steel industry and the burning of fuel oils.

The geochemical characteristics of V are dependent on its oxidation state (+2. +3, +4 and +5) and on soil acidity. V is known to form various cationic and anionic complexes, including vanadyl salts, hydrated oxides and vanadates. This enables V to display various types of behaviour in soil. It usually does not form its own minerals but instead replaces metals such as Fe, Ti and Al in crystal structures.

V compounds in soil are relatively stable with limited solubility in water, remaining in soil for a long period of time. The more mobile fraction of soil V is held by Fe and Mn oxides, clay minerals and organic acids. The vanadyl cation (VO^{3+}) is thought to be an important mobile form of V in soils.

Summary statistics are provided for each of the four countries in Table 4.20 and illustrated in Figure 4.1b.

Table 4.20 – Concentrations of V in rural soils of different countries in the UKSHS (mg/kg)#

Vanadium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	2.18–544	45.4	39.2	42.7
England	183	5.88–311	45.9[a]	41.5	34.2
N. Ireland	30	6.01–190	61.9[ab]	38.9	56.1
Scotland	120	2.18–544	43.2[b]	32.8	53.7
Wales	33	4.83–60.3	35.2[b]	36.3	15.3

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Although the range of concentrations of V in UK rural soils, considered as UK 'background' conditions in the UKSHS, was wider than the range of concentrations reported by Black *et al.* (2002) as being representative of soils of the British countryside, and also wider than the range reported by Alloway *et al.* (1998), the mean V concentrations were similar. Mean concentrations in Northern Ireland were significantly higher than those in England.

Table 4.21 compares these results to V concentrations in UK and world soils reported in other studies. The higher soil V values may be derived from soils developed on mafic rocks.

Kabata-Pendias (2000) reported a range of 0.7–320 mg/kg V for various world surface soils. Lis and Pasieczna (1995) reported that soils from lowland Poland contain HCl-soluble V below 10 mg/kg V and that mountain soils contained V in the range 10–20 mg/kg. The same authors reported V concentrations in soils to be <80 mg/kg in areas near to metal smelters in Poland and to be >80 mg/kg in the vicinity of an oil refinery.

The difference in V content, depending on extraction methods, suggests strongly bound forms of V in soils (Kabata-Pendias 2000). This is supported by Koljonen (1992), who reported the 90th percentile for acid soluble V in Finnish soils to be 60 mg/kg whereas the total V in soils is 120 mg/kg. Kadunas *et al.* (1999) reported the median concentration of V in Lithuanian soils to be 26 mg/kg.

Table 4.21 – Reported concentrations of V in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	2.18–544	45.4	39.2
Alloway *et al.* (1998)[1]	18.0–158.7	47.9	40.6
Archer (1963) (Wales)	15–200	–	–
Black *et al*. (2002)	1.8–174	40.2	38.8
Govindaraju (1994)[2]	37–247	–	–
Govindaraju (1994)[3]	36–150	–	–
Kabata-Pendias (2000)	0.7–320	–	–
Kadunas *et al.* (1999)[4]	–	–	26
Lis and Pasieczna (1995)[5]	10–20	–	–
Reimann *et al.* (2003)[6]	<1–203	24	18
Shacklette and Boerngen (1984)[7]	–	58	–
Ure *et al*. (1979) (podzols and sandy soils)	58–91	–	–
Ure and Bacon (1978) (soils on mafic rocks)	340–460	–	–

[1] Aqua regia extractable V in soils (0–20 cm) at 34 sites in England and Wales remote from obvious sources of pollution
[2] Reference soils from China
[3] Reference soils from the USA
[4] Lithuanian soils
[5] HCl-soluble V in mountain soils of Poland
[6] 750 topsoils in the Baltic Soil Survey
[7] Soils of the USA

Zinc (Zn)

Zn occurs naturally in rocks, soils, plants and animals, and is an essential trace element for both plants and animals. It enters the environment in atmospheric deposition from:

- mining
- the processing of non-ferrous metals
- the burning of coal and other fossil fuels
- the application of sewage sludge to land.

Ionic Zn is held by cation exchange on soil clay minerals and becomes more mobile and bio-available under acidic soil conditions (Ross 1994). Zn also forms soluble chelates with fulvic acids derived from soil organic matter. Zn can be leached from soils in soluble organic complexes and under acidic conditions.

Summary statistics are provided for each of the four countries in Table 4.22 and illustrated in Figure 4.1b. Table 4.23 compares UKSHS data with data from other surveys.

Table 4.22 – Concentrations of Zn in rural soils of different countries in the UKSHS (mg/kg)#

Zinc	*n*	Range	Mean	Median	SD
UK	366	2.63–442	81.3	65.9	576.0
England	183	17.7–442	94.8[a]	79.5	63.1
N. Ireland	30	24–184	81.9[a]	76.0	47.9
Scotland	120	2.63–211	58.6[b]	55.5	36.1
Wales	33	12–357	87.9[a]	73.0	66.6

Mean values in the same column followed by different letters are significantly different at *p* <0.05 or better.

Table 4.23 – Reported concentrations of Zn in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	2.63–442	81.3	65.9
Alloway *et al.* (1998)[1]	30.0–152.3	83.5	87.4
Archer and Hodgson (1987)	3.9–975	78.1	80.0
Ashmore *et al.* (2000)[2]	19–5,140	–	65.8
Black *et al.* (2002)	2.5–2,120	80.0	61.7
Holmgren *et al.* (1993)[3]	<3.0–264	56.5	53
Kabata-Pendias and Wiacek (1985)[4]	3–762	46.6	–
McGrath and Loveland (1992)	5.0–3648	97.1	82.0
Reimann *et al.* (2003)[5]	0.3–254	42	33

[1] Aqua regia extractable Zn in soils at 34 sites in England and Wales remote from obvious sources of pollution

[2] Upland soils in England and Wales

[3] 3,045 agricultural soils in the USA

[4] Surface soils in Poland

[5] Aqua regia extractable Zn in 750 topsoils in the Baltic Soil Survey

Mean Zn concentrations were significantly lower in Scottish rural soils than in England, Wales and Northern Ireland. The highest Zn maximum concentrations and the widest Zn concentration ranges were found in rural soils in England (Table 4.22). The mean value for the UK was almost the same as that reported previously by Alloway *et al.* (1998). Kabata-Pendias (2000) reported that the mean total Zn concentrations in surface soils in various countries range from 17 to 125 mg/kg and that a grand mean Zn concentration for worldwide soils has been calculated as 64 mg/kg.

The median Zn contents in both France and German soils in the European Soil Bureau (2000) data (Appendix 10) are lower than those reported here for the four UKSHS countries and the other values from the literature in Table 4.23 for the UK.

4.1.2 Other metals in rural soils

Tin (Sn)

Sn occurs naturally in rocks, soils, plants and animals. It is now considered to be one of the 17 elements essential for humans (Neilsen 1997). Tin can also enter the environment in atmospheric pollution from coal and oil combustion, mining and metal processing industries, the manufacture of tinplate and in fallout from nuclear testing. Tin can be associated with the operation of nuclear reactors and the reprocessing of nuclear fuels as ^{121}Sn and ^{126}Sn isotopes.

The main ore of tin, cassiterite (SnO_2), is strongly resistant to weathering. Sn is known to occur as Sn^{2+} and Sn^{4+}, and to form complex anions. Sn is held in soil by cation exchange on clay minerals. Under more acidic soil conditions, it can become more bioavailable and can be leached in drainage waters.

Summary statistics are provided for each of the four countries in Table 4.24 and illustrated in Figure 4.1a.

Table 4.24 – Concentrations of Sn in rural soils of different countries in the UKSHS (mg/kg)

Tin	*n*	Range	Mean	Median	SD
UK	366	2–115	3.91	2.00	9.37
England	183	2–115	5.05	2.13	12.71
N. Ireland	30	2–5.27	2.23	2.00	0.72
Scotland	120	2–8.43	2.44	2.00	1.15
Wales	33	2–46	4.44	2.59	7.68

The data in Table 4.24 largely reflect the limit of detection for Sn (2 mg/kg); accordingly no statistical analyses were performed.

The range of concentrations of Sn in UK rural soils, considered as UK 'background' conditions in the UKSHS, showed the highest concentrations to be in England. This is not surprising since mining of tin ore – principally of the tin oxide cassiterite – was an important industry in Cornwall and Devon for hundreds of years.

The high value of 115 mg/kg Sn at one site in England was probably due to mineralisation. The effect of this one site was to increase the mean and range of Sn concentrations in the English dataset. Without this site Sn concentrations in England would range from 2 to 45 mg/kg, but would still be generally higher than the range of Sn concentrations reported previously for generally uncontaminated soils (Table 4.25). One sub-sample from one site in Wales contributed a Sn concentration significantly higher than the rest of the Welsh data. No other surveys of tin in UK soils were found.

High Sn concentrations in rural soils are more likely to be due to dispersion from past mining activities than from smelting and other metal processing industries. Rural soil concentrations in Scotland and Northern Ireland were similar to those reported for generally uncontaminated soils in Northern France (Table 4.25).

Edwards *et al.* (1995) quote ranges of 1–4.6 mg/kg and 1–10 mg/kg Sn in non-contaminated soils but mention that values above 250 mg/kg are not uncommon in mineralised and contaminated soils. Kabata-Pendias and Pendias (1999) reported that, at some polluted sites, concentrations of Sn in soil can be up to 800 mg/kg.

Table 4.25 – Reported concentrations of Sn in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	2–115	3.91	2.00
Chapman (1972) (USA)	1–11	–	–
Govindaraju (1994)[1]	2.5–17.7	1.6	–
Govindaraju (1994)[2]	1.7–4.0	2.4	–
Kick *et al.* (1980) (Germany)	1–4	–	–
Presant (1971) (USA)	1.1–4.6	–	–
Reimann *et al.* (2003) (Baltic Soil Survey)[3]	<1–6.8	1.3	1.1
Sterckeman *et al*. (2002)[4](Northern France)	2.02–7.26	–	–
Sterckeman *et al*. (2002)[5] (Northern France)	1.36–3.20	–	–

[1] Reference soils from China
[2] Reference soils from the USA
[3] 750 topsoils (0–25 cm); (in HF)
[4] Contaminated soils
[5] Reference soils (loessic and alluvial)

Lead (Pb)

Pb occurs naturally in rock (and sulphide mineralisation), soils, plants and animals. There are also a number of anthropogenic sources in the environment such as atmospheric deposition from the combustion of leaded petrol in vehicles, combustion of coal, releases from lead-based paints, incineration of wastes, mining and metal processing industries and the application of sewage sludge to land.

Since the reduction in use of lead-based paints and fuels, atmospheric lead levels have declined, but soil concentrations are still high in places where traffic had been heavy in the past. Although road traffic studies have indicated that the bulk of soil Pb contamination from vehicle emissions does not extend significantly further than 30 m from the road, elevated background Pb contamination of soil and vegetation indicates that at least a proportion of lead aerosols emitted from vehicles and industry can be carried over much longer distances. Nicholson *et al.* (2003) presented a range of 6.3–139 g Pb/ha/year for Europe, with a European average of 38 g Pb/ha/year.

Lead and its compounds tend to accumulate in soils due to their low solubility and slow rates of microbial decomposition. In ionic form, Pb is held by:

- cation exchange on soil clay minerals;
- adsorption on naturally occurring iron oxides;
- complexing with humic compounds in soil.

Although Pb tends to be retained in soil, certain lead compounds become sparingly mobile and bio-available in acidic soil conditions. Under these conditions, there is a possibility that Pb could be leached from soils in drainage waters.

Summary statistics are provided for each of the four countries in Table 4.26 and illustrated in Figure 4.1b. Table 4.27 compares UKSHS data with data from earlier surveys.

Table 4.26 – Concentrations of Pb in rural soils of different countries in the UKSHS (mg/kg)#

Lead	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	2.6–713	52.6	37.4	66.8
England	183	16.2–713	62.0[a]	40.7	84.8
N. Ireland	30	11.2–108	30.1[b]	18.6	25.5
Scotland	120	2.6–294	41.9[b]	27.6	42.3
Wales	33	16.3–141	59.2[a]	46.3	35.7

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Table 4.27 – Reported concentrations of Pb in UK and world soils (mg/kg)

Reference	Range	Mean	Median
UKSHS	2.60–713	52.6	37.4
Abbott *et al.* (1997)	24–29	–	–
Alloway *et al.* (1998)[1]	18.4–142.4	44.4	37.7
Archer and Hodgson (1987)	4.5–2,900	39.8	36.8
Ashmore *et al*. (2000)	32–33,200	–	122
Black *et al*. (2002)	1.3–20,600	88.0	37.4
Fergusson (1990)	17–142	–	–
Holmgren *et al.*(1993)[2]	7.5–135	12.3	11.0
Kabata-Pendias and Wiacek (1985)[3]	5–286	18	–
McGrath and Loveland (1992)	3.0–16338	74.0	40.0

[1] Aqua regia extractable Pb in soils (0–20 cm) at 34 sites in England and Wales remote from obvious sources of pollution

[2] 3,045 agricultural soils in the USA

[3] Surface soils of Poland

Kabata-Pendias (2000) reported that baseline values for Pb in most world soils should not be much higher than 20 mg/kg. This conclusion followed from the work of Gough *et al*. (1988), who found a relatively low Pb content of soils in Alaska. Kabata-Pendias (2000) estimated the mean Pb concentration for surface soils on the world scale to be 25 mg/kg.

The median Pb values for the UK were of a similar order to those reported in the European Soil Bureau (2000) data for France and Germany (Appendix 10).

The general pattern of results is a probable reflection of the intensity of dispersion of lead from vehicular emissions before lead-free fuel was widely used. A few rural soil Pb values are also likely to come from locations near to Pb mining or metal processing plants where particulates and fallout from both past and present mining activities have contaminated the soil.

4.1.3 Metalloids in rural soils

Arsenic (As)

Arsenic occurs naturally in rocks, soils, plants and animals, but is not essential for either plants or animals. It enters the environment through weathering, combustion of fossil fuels, incineration of wastes and from use of As-based preservatives (timber) or pesticides.

Arsenic is strongly retained in anionic form in soil by adsorption onto compounds such as naturally occurring iron and aluminium oxides. Under oxidising and aerated conditions and at low pH, the predominant form of As in soil is arsenate. Under reducing and waterlogged conditions, arsenites should be the predominant As compounds. The rate of conversion is dependant on the pH of the soil. Under acidic, waterlogged conditions and in coarse sandy textured soils, As can be leached from soils in drainage waters.

Summary statistics provided for each of the four countries in Table 4.28 and illustrated in Figure 4.1a.

Table 4.28 – Concentrations of As in rural soils of different countries in the UKSHS (mg/kg)#

Arsenic	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	0.5–143	10.9	7.1	17.2
England	183	1.37–143	13.9[a]	8.3	22.2
N. Ireland	30	2.11–18.7	6.6[b]	4.5	5.0
Scotland	120	0.5–64.9	6.3[b]	4.3	7.6
Wales	33	3.09–56	14.7[a]	11.0	12.5

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Arsenic concentrations in UKSHS rural soils showed significant geographical variation, with significantly higher mean concentrations in England and Wales.

Table 4.29 compares the range of concentrations of As in UK rural soils, considered as UK 'background' conditions in the UKSHS, with the range of concentrations reported elsewhere for UK and world soils. Alloway *et al.* (1998) reported a similar mean concentration but with a narrower range of values.

Table 4.29 – Reported concentrations of As in UK and world soils (mg/kg)

Reference	**Range**	**Mean**	**Median**
UKSHS	0.50–143	10.9	7.1
Abbott *et al*. (1997)	5.5–8.8	7.4	–
Alloway *et al.* (1998)[1]	4.8–18.25	9.5	9.1
Archer and Hodgson (1987)	1.0–140	11.0	10.4
Culbard and Johnson (1984)	29–51	–	–
Fergusson (1990)	4.8–30	–	–
Kabata-Pendias and Pendias (1999)[2]	0.9–3.4	–	–
Reimann *et al*. (2003)[3].	<0.1–24	2.6	1.9

[1] Aqua regia extractable As in soils at 34 sites in England and Wales remote from obvious sources of pollution
[2] Soils in Poland
[3] Aqua regia extractable As in the 750 topsoil samples of the Baltic Soil Survey

4.1.4 Relationships between soil characteristics and heavy metals

The full dataset for the three soil properties (pH, organic matter and bulk density) and the qualitative descriptions of texture determined in rural soils collected from sites in England, Northern Ireland, Scotland and Wales ($n = 366$) is presented in UKSHS Report No. 1.

Descriptive statistics for the full soil properties dataset and for each of the regions (England, Northern Ireland, Scotland and Wales) can also be found in UKSHS Report No. 1.

4.1.5 Relationships between soil properties and heavy metals in rural soils

The distribution and behaviour of many trace metals in soil is determined by only a few soil properties – most importantly pH, organic matter and texture. This section provides a brief analysis of the overall patterns found in UK soils indicating relationships between soil properties and trace metals, and between different trace metals.

Correlation coefficients for soil properties and 11 trace metals and arsenic were calculated for all UK data and for England, Northern Ireland, Scotland and Wales individually. r^2 values and their associated probabilities are presented in Appendix 3. In these matrices, the r^2 value is the correlation coefficient, while probability values (p) at 0.001 per cent, 0.01 per cent and 0.05 per cent are indicated. The p value is the probability associated with rejection of the null hypothesis in the correlation analysis. A value of $p = 0.001$, for example, indicates that, on 0.001 per cent of occasions, the null hypothesis that there is no relationship between metal concentrations in soil and herbage will be rejected when in fact the null hypothesis is true. This is a very low error level, equating to once in 100,000 times.

Soil pH

A strong relationship is expected between pH and those trace metals whose solubility and/or mobility depends on pH (e.g. Cu, Hg, Pb, As) or which are exchanged by cation exchange processes – namely Cd, Cr, Mn, Ni, Zn, Sn and Pb.

A number of correlations of varying degrees of significance were found between pH and the 12 trace metals/metalloid (excluding Pt) when the whole UK rural soil dataset was analysed (the full r^2 values are provided in Appendix 3, including the significance of correlations). Similarly, a number of significant correlations were found between soil pH and the 13 trace metals/metalloid when the data for each of the four countries were analysed separately.

In the overall UK dataset, a positive correlation was found between pH and Zn ($p = 0.01$).

When the four regions' data were inspected individually, positive correlations were observed between:

- pH and Cd ($p = 0.05$) in England;
- pH and Pb ($p = 0.001$), Zn ($p = 0.001$), Cr ($p = 0.01$), Ni ($p = 0.01$) and V ($p = 0.01$) in Northern Ireland;
- pH and Hg ($p = 0.001$), Cr ($p = 0.01$), Sn ($p = 0.05$), Ti ($p = 0.05$) and Zn ($p = 0.05$) in Scotland;
- pH and Cr ($p = 0.001$), Mn ($p = 0.001$), Ni ($p = 0.001$), V ($p = 0.001$) and Zn ($p = 0.001$) in Wales.

Significant negative correlations were observed between pH and Pb ($p = 0.01$) and Cr ($p = 0.05$).

These results generally confirm the pH-dependency of retention in soil of ionic forms of Pb, Cr, Zn and to a lesser extent Cd. Not surprisingly, since the UKSHS results are **total** concentrations of metals in soil, some of the expected relationships were not observed.

Soil organic matter

A strong relationship might be expected between soil organic matter (OM) and trace metals that are adsorbed onto soil organic matter or which form humic complexes or organic chelates (e.g. Cu, Hg, Pb). A weaker relationship might be expected between soil organic matter and those metals that are exchanged by cation exchange processes (a portion of which is provided from soil organic matter) – namely Cd, Cr, Mn, Ni, Zn, Sn and Pb.

A number of correlations of varying degrees of significance were found between soil organic matter content and the 12 trace metals/metalloid (excluding Pt) when the whole UK rural soil dataset was analysed (the full r^2 values are provided in Appendix 3, including the significance of correlations). Similarly, a number of significant correlations were found between soil OM and the 12 trace metals/metalloid when the data for each of the four countries were analysed separately.

In the overall UK dataset, a positive correlation was found between soil organic matter and Hg ($p = 0.001$). When the four regions' data were inspected individually, positive correlations were observed between:

- OM and Cr ($p = 0.001$), Ni ($p = 0.001$), V ($p = 0.001$), As ($p = 0.01$), Mn ($p = 0.01$) and Zn ($p = 0.01$) in England;
- OM and Cd ($p = 0.001$) and Hg ($p = 0.001$) in Northern Ireland;
- OM and Cd ($p = 0.001$), Pb ($p = 0.001$), Hg ($p = 0.001$) and Sn ($p = 0.001$) in Scotland;
- OM and Mn ($p = 0.001$), Pb ($p = 0.05$) and Hg ($p = 0.05$)) in Wales.

Significant negative correlations were observed between:

- OM and Cu ($p = 0.001$) in Northern Ireland;
- OM and Cr ($p = 0.001$), V ($p = 0.01$) and Ti ($p = 0.05$) in Scotland;
- OM and Cr ($p = 0.001$), Ni ($p = 0.001$) and V ($p = 0.001$) in Wales.

These results generally indicate the role of soil organic matter in cation exchange processes and involving chelation of specific metals such as Hg. The lack of significant positive correlations between OM and Cu and the negative correlation between OM and Cu in Northern Ireland are very difficult to explain since the strong relationship between Cu and soil organic matter and the formation of copper chelates in soils is well known.

4.1.6 Relationships among heavy metals/metalloid in rural soils

A large number of correlations of varying degrees of significance were found among the 12 trace metals/metalloids (excluding Pt) when the whole UK rural soil dataset was analysed (the full r^2 values are provided in Appendix 3, including the significance of correlations). Similarly, a large number of significant correlations were found among the 12 trace metals/metalloids when the data for each of the four countries were analysed separately.

This is not surprising for several reasons. First, many naturally occurring ores in the Earth's crust are composed of combinations of trace metals and a relationship between them would be expected. For the same reason, several trace metals may be found together in fallout from metal processing industries (e.g. the presence of Pb, Zn and Cd together in lead carbonate ores). Secondly, several metals in ionic form are retained in soil by similar adsorption processes. Thirdly, several ionic species are adsorbed onto the surfaces of Fe and Mn oxides in soil, so a positive correlation between Mn and several trace metals might be expected.

Using only the overall UK dataset, the most significant positive correlations were observed between:

- Zn with As, Cd, Cr, Cu and Pb;
- Cr with Cu, Ni, Ti, V and Zn;
- Cu with Mn, Hg, Ni, Ti and Zn.

The first confirms the expected relationship between Pb, Zn and Cd. However, only two trace metals (Hg and Zn) correlate (at $p = 0.01$) with Mn. The range of V concentrations in rural soils is higher than found in previous UK surveys.

4.1.7 Conclusions on heavy metals in rural soils

The majority of trace metals (Cd, Cr, Cu, Hg, Ni, Zn, Pb) in rural soils were present in concentrations that are within the ranges reported in previous surveys of generally uncontaminated UK soils.

However, there were significant geographical variations in rural soil concentrations across the four countries in the UKSHS:

- mean concentrations of Cr and Cu are significantly higher in Northern Ireland than in the other three countries;
- Ti is significantly higher in Northern Ireland and Scotland than in England and Wales;
- Pb and As are significantly lower in Northern Ireland and Scotland.

Other more complex comparisons are best studied by reference to the individual tables of this report.

4.2 Soils from urban locations

The full dataset for the concentrations of the 13 heavy metals and metalloids determined in soils collected from sites in 29 towns and cities in England, Northern Ireland, Scotland and Wales (n = 87) is given in Appendix 2 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of soil.

Descriptive statistics for the full dataset and for each of the regions (England, Northern Ireland, Scotland and Wales) are presented in this section of the report as separate tables for each of the elements studied. This section discusses general levels and patterns of trace metals in urban soils. Results are compared to rural soil concentrations and to previous studies of trace metals in urban soils.

4.2.1 Transition metals

Cadmium (Cd)

Summary statistics are provided for each of the four countries in Table 4.30 and illustrated in Figure 4.2c.

Table 4.30 – Concentrations of Cd in urban soils of different countries in the UKSHS (mg/kg)#

Cadmium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	87	0.10–2.39	0.44	0.29	0.41
England	42	0.10–2.39	0.53^{a}	0.33	0.50
N. Ireland	18	0.10–1.00	0.28^{c}	0.15	0.30
Scotland	18	0.11–0.62	0.28b^{c}	0.26	0.14
Wales	9	0.26–1.23	0.62^{a}	0.54	0.36

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Cd concentrations in UKSHS urban soils was a little higher than in rural soils (0.10–1.80 mg/kg) (Table 4.1) but low compared with concentrations reported in many previous surveys of UK soils (Table 4.2). They can be compared with the range of <0.5–3.0 mg/kg found in urban soils in south Dudley (Allan *et al.* 1999) and the range of <0.2–5.9 mg/kg found in a survey of urban garden soils in England by Moir and Thornton (1989).

Mean concentrations of Cd in urban soils showed samples from Wales as having higher levels of cadmium than the samples collected in Northern Ireland and Scotland.

The cadmium data for French and German garden soils are generally similar to the concentrations found in the UKSHS urban soils, but the maximum concentrations are much higher in both the French and German soils (Table 4.31).

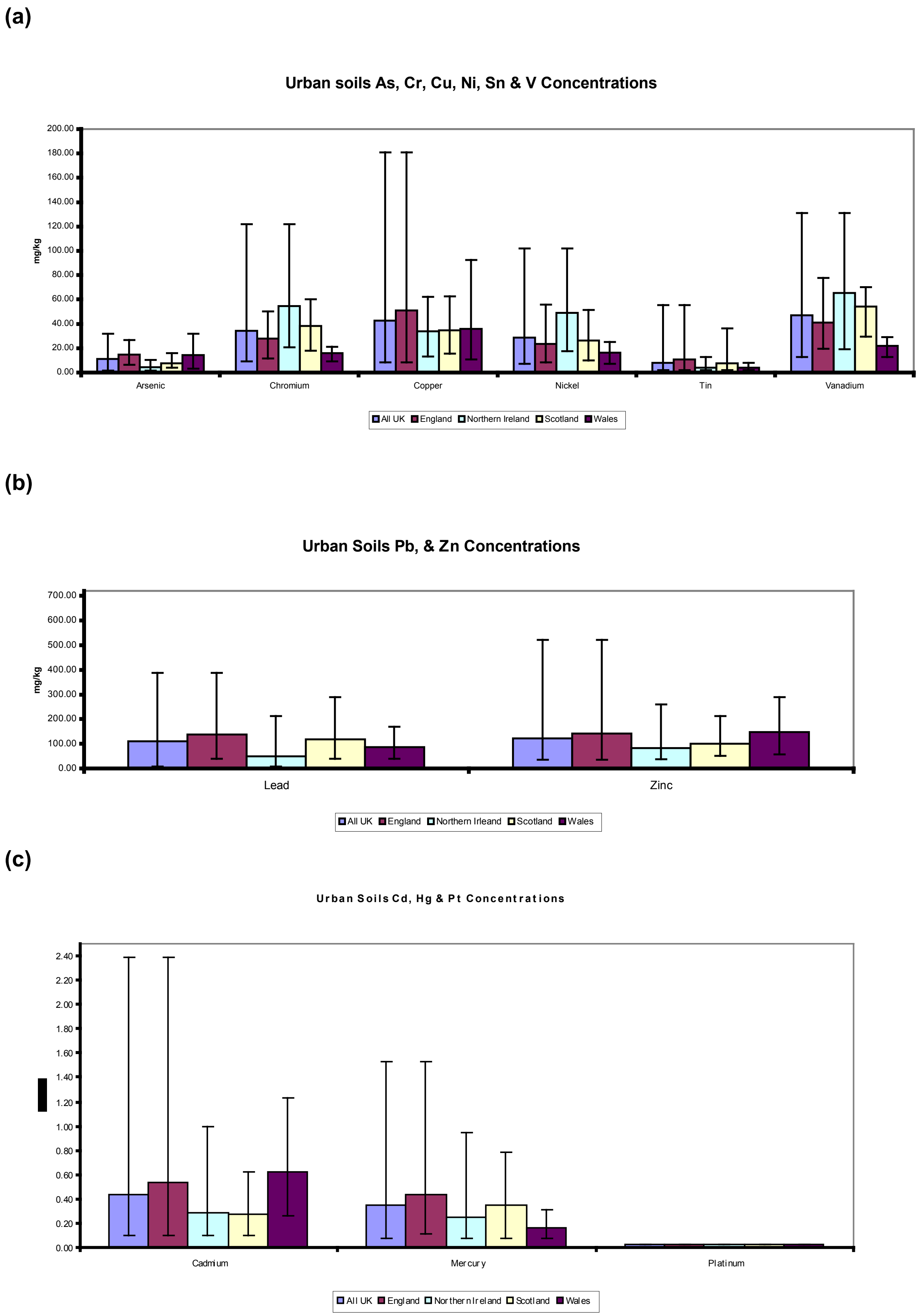


Figure 4.2 – Means and ranges of metal/metalloid concentrations in urban soils

Table 4.31 – Concentrations of Cd in French and German garden soils (mg/kg)

Reference	Maximum concentration	Mean
Gröβmann and Wüstermann (1992)[1]	7.3	0.5
Schwartz *et al.* (2000)[2]	5.3	1.0

[1] 3,624 garden soils in Germany
[2] 105 garden soils in France

Chromium (Cr)

Summary statistics are provided for each of the four countries in Table 4.32 and illustrated in Figure 4.2a.

Table 4.32 – Concentrations of Cr in urban soils of different countries in the UKSHS (mg/kg)#

Chromium	*n*	Range	Mean	Median	SD
UK	87	9.1–122	34.3	27.3	21.6
England	42	11.6–50.3	27.8[a]	24.5	9.17
N. Ireland	18	20.6–122	54.7[c]	43.0	34.5
Scotland	18	17.8–60	38.3[c]	44.2	14.4
Wales	9	9.1–21	16.1[b]	19.0	5.05

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of Cr concentrations in UKSHS urban soils was narrower than in UK rural soils (1.14–236 mg/kg) (Table 4.4) and also generally low compared with concentrations reported for UK soils (Table 4.5). Only in Scotland were mean urban soil Cr concentrations a little higher than mean rural soils Cr concentrations.

Overall, the range of Cr concentrations in UKSHS urban soils was a little greater than the range of concentrations found in urban soils in south Dudley (15–64 mg/kg) (Allan *et al.* 1999). Mean Cr concentrations in urban soils were significantly higher in Northern Ireland than in Scotland and England, which in turn were significantly higher than in Wales. This trend mirrors that seen for rural soils. The higher Cr concentrations found in Northern Ireland could be due to the geochemistry of the mafic rocks, which crop out there.

Copper (Cu)

Summary statistics are provided for each of the four countries in Table 4.33 and illustrated in Figure 4.2a.

Table 4.33 – Concentrations of Cu in urban soils of different countries in the UKSHS (mg/kg)#

Copper	*n*	Range	Mean	Median	SD
UK	87	8.27–181	42.5	30.4	36.6
England	42	8.27–181	51.0[a]	31.8	47.7
N. Ireland	18	13.2–62.3	33.9[a]	27.4	19.3
Scotland	18	15.5–62.7	34.8[a]	28.7	13.3
Wales	9	10.8–92.5	35.8[a]	23.1	29.7

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of Cu concentrations in urban soils in the UKSHS was almost twice that in rural soils (2.27–96.7 mg/kg) (Table 4.7). Cu concentrations in urban soils were generally within the range of Cu values in UK soils reported previously (Table 4.8).

- The English cities and towns in this study had higher mean soil Cu concentrations than in the other three countries.
- The range of values and the mean Cu concentration for urban soils in England were higher than for rural soils.
- The mean Cu concentrations for rural and urban soils in Northern Ireland were similar.
- The mean Cu concentrations for urban soils in Scotland and Wales were higher than for rural soils.

Overall, the range of Cu concentrations in UKSHS urban soils was very similar to the range of concentrations found in urban soils in south Dudley (17–190 mg/kg) (Allan *et al.* 1999).

The mean copper concentrations in the UKSHS urban soils were higher than for garden soils in both France and Germany (Table 4.34).

Table 4.34 – Concentrations of Cu in French and German garden soils (mg/kg)

Copper	Maximum concentration	Mean
Gröβmann and Wüstermann (1992)[1]	196	24
Schwartz *et al.* (2000)[2]	181	27.3

[1] 3,624 garden soils in Germany
[2] 105 garden soils in France

Manganese (Mn)

Summary statistics are provided for each of the four countries in Table 4.35.

Table 4.35 – Concentration of Mn in urban soils of different countries in the UKSHS (mg/kg)#

Manganese	*n*	Range	Mean	Median	SD
UK	87	98.3–2,100	502	386	368
England	42	98.3–2,100	495[a]	317	449
N. Ireland	18	243–789	465[a]	370	197
Scotland	18	282–936	467[a]	397	181
Wales	9	148–1,320	676[a]	665	480

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Mn concentrations in UKSHS urban soils was narrower than the range of Mn concentrations in rural soils (10–12,200 mg/kg) (Table 4.9) and also generally much lower than concentrations reported previously for UK soils (Table 4.10). However, the high range for the rural samples was due to individual results in Scotland, which may reflect local geology. The mean Mn concentration in urban soils was higher in Wales than in the other countries. The mean Mn concentrations in urban soils in England, Northern Ireland and Scotland were fairly similar.

Overall, the mean and range of Mn concentrations in UKSHS urban soils were significantly higher than the mean and range of concentrations found in urban soils in south Dudley (326 and 130–460 mg/kg respectively) (Allan *et al.* 1999).

Mercury (Hg)

Summary statistics provided for each of the four countries in Table 4.36 and illustrated in Figure 4.2c. Note that the limit of detection for mercury in soil is 0.07 mg/kg.

Table 4.36 – Concentrations of Hg in urban soils of different countries in the UKSHS (mg/kg)#

Mercury	*n*	Range	Mean	Median	SD
UK	87	0.07–1.53	0.35	0.23	0.29
England	42	0.12–1.53	0.43^{a}	0.39	0.20
N. Ireland	18	0.07–0.95	0.25^{b}	0.13	0.32
Scotland	18	0.07–0.78	0.35^{a}	0.24	0.26
Wales	9	0.07–0.31	0.16^{b}	0.14	0.09

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Hg concentrations in UKSHS urban soils was a little wider than the range of concentrations found in rural soils (0.07–1.22 mg/kg) (Table 4.11).

There are few previous surveys reporting Hg concentrations in urban soils throughout the UK. The mean and range of Hg concentrations in urban soils were similar to those reported for urban sites in south Dudley (0.34 and <0.2–1.2 mg/kg Hg respectively) (Allan *et al*. (1999).

Mean Hg concentrations were significantly higher in English urban soils than in Wales, with Northern Ireland and Scotland at intermediate levels.

Nickel (Ni)

Summary statistics provided for each of the four countries in Table 4.37 and illustrated in Figure 4.2a.

Table 4.37 – Concentrations of Ni in urban soils of different countries in the UKSHS (mg/kg)#

Nickel	*n*	Range	Mean	Median	SD
UK	87	7.07–102	28.5	22.0	21.9
England	42	8.5–55.8	23.3^{cd}	17.8	13.1
N. Ireland	18	17.6–102	49.0^{a}	29.60	35.9
Scotland	18	9.9–51.3	26.2^{bd}	27.2	10.6
Wales	9	7.07–25.1	16.3^{c}	18.6	7.4

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Ni concentrations in UKSHS urban soils was narrower than the range of Ni concentrations in UKSHS rural soils (1.16–216 mg/kg) (Table 4.14), and generally lower than the concentration ranges reported generally for UK soils (Table 4.15).

Overall, the range of Ni concentrations in UKSHS urban soils was wider than the range of concentrations found in urban soils in south Dudley (8–44 mg/kg) (Allan *et al.* 1999). Mean Ni concentrations were also a little higher than those in the south Dudley survey.

Mean Ni concentrations in Northern Ireland soils were significantly higher than in the other three countries.

With the exception of Wales, the mean nickel concentrations in the UKSHS urban soils were higher than those found for garden soils in both France and Germany (Table 4.38).

Table 4.38 – Concentrations of Ni in French and German garden soils (mg/kg)

Nickel	Maximum concentration	Mean
Gröβmann and Wüstermann (1992)[1]	69	14
Schwartz *et al.* (2000)[2]	56.4	19.3

[1] 3,624 garden soils in Germany
[2] 105 garden soils in France

Platinum (Pt)

Summary statistics are provided for each of the four countries in Table 4.39 and illustrated in Figure 4.2c.

These data reflect the limit of detection for platinum in soil; no statistical analyses were performed on these data.

Table 4.39 – Concentrations of Pt in urban soils of different countries in the UKSHS (mg/kg)

Platinum	*n*	Range	Mean	Median	SD
UK	87	0.02–0.02	0.02	0.02	0.00
England	42	0.02–0.02	0.02	0.02	0.00
N. Ireland	18	0.02–0.02	0.02	0.02	0.00
Scotland	18	0.02–0.02	0.02	0.02	0.00
Wales	9	0.02–0.02	0.02	0.02	0.00

There are few data worldwide on soil Pt concentrations to use as a benchmark when interpreting the UKSHS results. However, the range of concentrations of Pt in UKSHS urban soils was relatively low compared with concentrations reported in urban roadside soils and road dusts (Table 4.17). In East Kilbride, Pt concentrations in road dust in residential areas (0.002–0.012 mg/kg) were reported to be much lower than for dual carriageways and motorways (Higney *et al.* 2002).

Titanium (Ti)

Summary statistics are provided for each of the four countries in Table 4.40.

Table 4.40 – Concentrations of Ti in urban soils of different countries in the UKSHS (mg/kg)#

Titanium	*n*	Range	Mean	Median	SD
UK	87	45.6–1,1400	693	181	1702
England	42	45.6–355	153[b]	157	68
N. Ireland	18	130–11,400	2,236[a]	680	3331
Scotland	18	373–1,510	711[a]	597	325
Wales	9	65.5–114	87[c]	86	14.6

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The few soil Ti data that are available worldwide show that Ti is an abundant element in soil with concentrations typically of around 1,000–3,600 mg/kg (Table 4.19). The range of concentrations of Ti in UKSHS urban soils was much wider than this and wider than the range of concentrations found in rural soils (12.7–3,280 mg/kg) (Table 4.18) due to very high results from one location in Northern Ireland. Despite this, upper Ti concentrations and Ti maximum values in the UKSHS were still 10 times lower than those reported for contaminated soils in California (Table 4.19).

Mean Ti concentrations in Northern Ireland urban soils were significantly higher than those in England.

Vanadium (V)

Summary statistics provided for each of the four countries in Table 4.41 and illustrated in Figure 4.2a.

Table 4.41 – Concentrations of V in urban soils of different countries in the UKSHS (mg/kg)#

Vanadium	***n***	**Range**	**Mean#**	**Median**	**SD**
UK	87	12.8–131	46.8	43.0	24.7
England	42	19.5–77.5	41.1[a]	41.3	11.6
N. Ireland	18	19–131	65.4[c]	44.9	41.6
Scotland	18	29.4–70	54.3[c]	58.5	13.0
Wales	9	12.8–29.1	21.9[b]	25.8	6.8

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of V concentrations in UKSHS urban soils was lower than the range of concentrations found in rural soils (2.18–544 mg/kg) (Table 4.20) and somewhat lower than the range reported by Black *et al*. (2002) as being representative of soils of the British countryside (Table 4.21). Mean V concentrations in Northern Ireland and Scotland were higher than those in England, which in turn were significantly higher than those in Wales.

Zinc (Zn)

Summary statistics provided for each of the four countries in Table 4.42 and illustrated in Figure 4.2b.

Table 4.42 – Concentrations of Zn in urban soils of different countries in the UKSHS (mg/kg)#

Zinc	***n***	**Range**	**Mean**	**Median**	**SD**
UK	87	35.1–521	121.5	95.1	89.9
England	42	35.1–521	142.2[a]	112	109
N. Ireland	18	36.7–260	82.1[b]	75.6	53.1
Scotland	18	51–212	99.9[b]	96.2	46.5
Wales	9	56.4–290	147[a]	137	83.9

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Zn concentrations in UKSHS urban soils was a little wider than the range found in rural soils (2.63–442 mg/kg) (Table 4.22), but much lower than the range of concentrations reported elsewhere in UK soils (Table 4.23). The range of Zn concentrations in urban soils was also lower than that reported for south Dudley (<66–680 mg/kg) by Allan *et al*. (1999).

Mean Zn concentrations in England and Wales urban soils were significantly higher than those in Northern Ireland. The data for garden soils in France and Germany (Table 4.43) showed mean values of Zn of a similar order to those found in urban soils in England and Wales. However, they were higher than those for urban soils in Northern Ireland and Scotland.

Table 4.43 – Concentrations of Zn in French and German garden soils (mg/kg)

Reference	Maximum concentration	Mean
Gröβmann and Wüstermann (1992)[1]	1,035	151
Schwartz *et al.* (2000)[2]	518	138

[1] 3,624 garden soils in Germany
[2] 105 garden soils in France

4.2.2 Other metals in urban soils

Tin (Sn)

Summary statistics are provided for each of the four countries in Table 4.44 and illustrated in Figure 4.2a.

Table 4.44 – Concentrations of Sn in urban soils of different countries in the UKSHS (mg/kg)#

Tin	*n*	Range	Mean	Median	SD
UK	87	2–55.3	8.06	5.41	8.9
England	42	2–55.3	10.8[a]	6.96	10.9
N. Ireland	18	2–12.7	3.90[b]	2.15	3.61
Scotland	18	2–36.3	7.66[a]	5.87	7.58
Wales	9	2–8.05	4.16[b]	3.75	2.20

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

No other surveys of tin in UK soils were found. The concentrations of Sn given in Table 4.44 are influenced by the limit of detection for Sn (2 mg/kg).

The range of Sn concentrations in UKSHS urban soils was lower than the range reported for rural soils (2–115 mg/kg) (Table 4.24), but higher than the concentrations found in urban soils in south Dudley (all <0.5 mg/kg) (Allan *et al.* 1999).

The range of concentrations of Sn in UKSHS urban soils showed the highest concentrations to be in cities and towns in England. Maximum Sn concentrations in urban soils in England and Scotland were higher than those reported around Pb/Zn smelters in northern France (Table 4.25).

Lead (Pb)

Summary statistics are provided for each of the four countries in Table 4.45 and illustrated in Figure 4.2b.

Table 4.45 – Concentrations of Pb in urban soils of different countries in the UKSHS (mg/kg)#

Lead	*n*	Range	Mean	Median	SD
UK	87	8.6–387	110	90.2	80.9
England	42	40.1–387	137[a]	115	85.3
N. Ireland	18	8.6–212	49.9[c]	34.8	55.7
Scotland	18	39.8–290	118[ab]	90.8	73.4
Wales	9	38.7–169	86.4[b]	82.3	46.9

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of Pb concentrations in UKSHS urban soils was much narrower than the range of concentrations found in rural soils (2.6–713 mg/kg) (Table 4.26) and much lower than Pb concentrations reported generally for urban soil conditions elsewhere in UK (Table 4.46). Mean Pb urban concentrations in England and Scotland were significantly higher than those in Northern Ireland.

The mean Pb concentrations in the UKSHS urban soils in England and Scotland were significantly higher than those reported in garden soils in France and Germany, but the mean Pb concentration in urban soils for the whole of the UKSHS was similar to the mean concentration reported for urban Stockholm (Linde 2001) (Table 4.46).

Table 4.46 – Reported concentrations of Pb in urban soils (UK and elsewhere) (mg/kg)

Reference	**Location**	**Range**	**Mean**
UKSHS	Urban soils	8.6–387	110
Allan *et al.* (1999)	South Dudley	33–430	156
Gröβmann and Wüstermann (1992)[1]	Germany	– 627	65
JURUE (1982)[2]	Soils in Walsall, West Midlands	8–2,575	
Linde *et al.* (2001)	Urban Stockholm	Max: 444	104
Schwartz *et al.* (2000)[2]	France	–340	58.7
Thornton *et al*. (1990)	UK urban gardens	–	230
Thornton *et al*. (1990)	UK urban vegetable plots	–	236
Thornton *et al*. (1990)	UK urban parks	–	170
Thornton *et al*. (1990)	London gardens	60–13,700	654
Thornton *et al*. (1990)	London vegetable plots	137–2,560	571
Thornton *et al*. (1990)	London parks	28–1,260	294

[1] 3,624 garden soils in Germany

[2] These old data relate to a time when Pb was still being used in petrol in relatively high concentrations and so are not strictly comparable to UKSHS data on samples collected more than 20 years later when Pb is no longer added to petrol.

[3] 105 garden soils in France

4.2.3 Metalloids in urban soils

Arsenic (As)

Summary statistics are provided for each of the four countries in Table 4.47 and illustrated in Figure 4.2a.

Table 4.47 – Concentrations of As in urban soils of different countries in the UKSHS (mg/kg)#

Arsenic	***n***	**Range**	**Mean**	**Median**	**SD**
UK	87	1.75–32	11.0	9.78	6.95
England	42	6.54–26.8	14.6^{a}	12.7	5.92
N. Ireland	18	1.75–10.3	4.58^{c}	4.29	2.47
Scotland	18	3.82–16	7.54^{b}	6.3	3.39
Wales	9	3.06–32	14.2^{ab}	12.2	10.2

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of concentrations of As in UKSHS urban soils was much lower than found in rural soils (0.5–143 mg/kg) (Table 4.28), but very similar to the range of soil As concentrations reported in south Dudley (<3–29 mg/kg) by Allan *et al.* (1999). Mean urban concentrations of As in England

and Wales were significantly higher than those in Scotland, which in turn were significantly higher than those in Northern Ireland.

Much higher concentrations of As have been reported for contaminated soils; for example, Lis and Pasieczna (1995) reported that polluted soils in industrial areas of Poland can contain As concentrations of over 650 mg/kg. Vangronsveld (1998) reported concentrations of up to 200 mg/kg in garden soils located in the vicinity of a former As smelter. Thornton and Farago (1997) reviewed soil As distribution in garden soils, reporting concentrations in the soils of up to about 15,000 mg/kg.

4.2.4 Conclusions on metals in urban soils

As for rural soils, there are some clear geographical variations in urban soil concentrations. Cr, Ti and V were significantly higher in Northern Ireland than in England and Wales, although the very high mean Ti concentration in Northern Ireland should be treated with caution as it largely reflected one site. Ni was significantly higher in Northern Ireland than in the other three countries. Conversely, As was lower in Northern Ireland urban soils than in the other three countries. Overall, the trends in urban soils mirrored those in rural soils.

The concentrations of Cd, Cu, Ni, Pb and Zn were of the same order as those found in garden soils in France and Germany but, in some cases, the mean concentrations were higher in some countries in the UKSHS data.

4.3 Soils from industrial locations

The full dataset for the concentrations of the 13 heavy metals and metalloids determined in soils collected from 54 industrial sites in England, Northern Ireland, Scotland and Wales is presented in Appendix 4 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of soil.

At each of the industrial sites, one sample was collected ‘upwind’ of the site and three samples were collected at 5, 10 and 15 effective stack heights ‘downwind’ of the site. But where the upwind sites contain higher concentrations than downwind sites, there is sometimes the possibility of contamination from previous use of the site or from other sources.

Each site was classified according to its type in one of the following classes:

- chemical industry (*n* = 3);
- general Industry (*n* = 1);
- incineration (*n* = 8);
- mineral industry (*n* = 6);
- non-ferrous metal industry (*n* = 6);
- oil refinery (*n* = 4);
- paper industry (*n* = 1);
- power station (*n* = 10);
- steel industry (*n* = 8);
- tar and bitumen industry (*n* = 1);
- textile industry (*n* = 1).

The results for industrial soils are discussed in the next section in comparison with those from urban and rural soils.

4.3.1 Comparison of soil heavy metal concentrations at rural, urban and industrial sites

Table 4.48 summarises the mean values for the 13 metals/metalloids in rural, urban and industrial sites. No analysis was performed on platinum data as the results were at or below LOD.

Table 4.48 – Mean soil metal/metalloid concentrations at rural, urban and industrial sites in the UKSHS (mg/kg)

	Rural	Urban	Industrial
Arsenic	10.9	11.0	18.1**
Cadmium	0.39	0.44	1.33**
Chromium	34.4	34.3	41.1*
Copper	20.6	42.5**	59.9**
Lead	52.5	110**	145**
Manganese	612	502	713
Mercury	0.13	0.35**	0.33**
Nickel	21.1	28.5*	37.1**
Platinum	–	–	–
Tin	3.91	8.06**	8.08**
Titanium	369	693*	332
Vanadium	45.4	46.8	55.2*
Zinc	81.2	121**	211**

* Significant difference from rural data at $p < 0.05$
** Significant difference from rural data at $p < 0.01$

- Comparison of mean values indicates that Cu, Pb, Hg, Ni, Sn and Zn all showed significantly elevated soil concentrations at both urban and industrial sites compared with the rural data. On average, urban and industrial soil concentrations of Cu, Pb, Hg and Sn were 2–3 times those in rural soils.
- Concentrations of As, Cd and V were only significantly greater than background in industrial soils.
- Chromium concentrations were not significantly different in rural, urban or industrial soils.

More detailed probing of the data requires care as the statistical robustness drops off rapidly. Several relationships between rural and urban soils are indicated in the data.

- The high Ti concentrations seen in urban soils in Northern Ireland and Scotland were also seen in high Ti concentrations in Northern Ireland and Scottish rural soils.
- The higher Ni and Cr in urban soils in Northern Ireland were also seen in rural soils in Northern Ireland.
- Higher As concentrations in urban soils in England and Wales were also seen in rural soils in England and Wales.

Information on heavy metals in industrial soils was published by the Contaminated Land and Liabilities Division of the then Department of the Environment (DoE) as 'Industry Profiles' in 1996. There are separate booklets for different industries in this series, including 14 on different types of chemical works (see http://www.defra.gov.uk/environment/land/contaminated/pubs.htm).

4.3.2 European soils

Data from the European Soil Bureau (2000) are given in Appendix 10 for comparison.

4.4 Semi-quantitative scan of metals in soils from industrial sites

Using inductively coupled plasma mass spectrometry (ICPMS), 37 little-analysed elements (Table 4.49) were scanned and semi-quantitative results reported on industrial soils and a few selected rural and urban soil samples.

Many of these elements have rarely been studied in any detail in the environment. The purpose of this determination is to identify:

- likely indicative levels of these elements in UK soils, particularly around industrial sites;
- any patterns of occurrence, e.g. among the lanthanide group.

These results are considered to be ‘semi-quantitative’. The full dataset of results for rural, urban and industrial soils is presented in Appendix 9 where a number of results are reported as ‘not detected’ (ND). In the ICPMS semi-quantitative scan, ‘non-detection’ can arise for two reasons – either the concentration is below the LOD or the semi-quantitative software is unable to distinguish the element from some of the matrix components. The latter is more likely for lighter transition elements such as Ti, V, or Cr rather than the elements considered in this section.

Table 4.49 – Elements studied semi-quantitatively in UK industrial soils

Lithium	Yttrium	Cerium	Erbium
Beryllium	Zirconium	Praseodymium	Thulium
Boron	Niobium	Neodymium	Ytterbium
Scandium	Molybdenum	Samarium	Lutetium
Cobalt	Silver	Europium	Tungsten
Gallium	Antimony	Gadolinium	Thallium
Germanium	Caesium	Terbium	Bismuth
Selenium	Barium	Dysprosium	Thorium
Rubidium	Lanthanum	Holmium	Uranium
Strontium			

Despite the semi-quantitative nature of the results, the concentration ranges quoted give a good indication of likely concentrations of elements to be found in UK industrial soils. They can be used to identify whether these soils are generally lower or higher than previously published concentrations of these elements in soils elsewhere in the UK or worldwide.

Since there are few previously published data on some of these elements, reliance is placed on a range of different sources for comparative purposes. These include:

- reviews of past data;
- early analytical suites using new analytical technologies;
- a single analytical source (in the case of previously reported data for British soils).

Despite this, the following assessment of elements in UK industrial soils and a few rural and urban soils gives a good indication of the general ranges of concentrations to be found at these sites and identifies locations where further investigation may be required.

The following sections describe and briefly compare levels of soil trace elements at industrial sites in the following order of the Periodic Table:

- **Group I elements –** lithium (Li), rubidium (Rb), caesium (Cs), silver (Ag);
- **Group II elements** – beryllium (Be), strontium (Sr), barium (Ba);

- **Group III elements** – boron (B), gallium (Ga), thallium (Tl), scandium (Sc), yttrium (Y);
- **Lanthanides** – lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu);
- **Actinides** – thorium (Th), uranium (U);
- **Group IV elements** – germanium (Ge), zirconium (Zr);
- **Group V elements** – antimony (Sb), bismuth (Bi), niobium (Nb);
- **Group VI elements** – selenium (Se), molybdenum (Mo), tungsten (W);
- **Group VIII elements** – cobalt (Co).

4.4.1 Group I elements (Li, Rb, Cs, Ag)

The alkali trace elements do not normally form complex ionic species.

Lithium

Li is a naturally occurring element. It is widely distributed in the Earth's crust, mainly concentrated in acid igneous rocks and sedimentary aluminosilicates. The Li concentration of soils is largely related to its concentration in rocks. Once mobilised during weathering, Li becomes firmly fixed on clay minerals. Exchangeable Li is strongly associated with calcium (Ca) and magnesium (Mg).

Kabata-Pendias (2000) reported Li concentrations in world soils (Table 4.50) to range from 0.01–175 mg/kg, with low concentrations in organic soils (1.2 mg/kg) and higher concentrations in alluvial soils (98 mg/kg). In US soils, the reported range is 0.7–88 mg/kg. Average Li concentrations in reference soils of the USA and China are reported to be 33 mg/kg and 35 mg/kg respectively. In the UK, the only reported soil Li concentration is reported 25 mg/kg (Ure and Bacon 1978).

Table 4.50 – Range of Li concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Li concentration
Govindaraju (1994)	Soils in USA	33
Govindaraju (1994)	Soils in China	35
Kabata-Pendias (2000)	General range worldwide	0.01–175
Kabata-Pendias (2000)	Soils in USA	0.7–88
Kabata-Pendias (1995)	Soils in Poland	0.01–38
Ure and Bacon (1978)	British soil	25

The full data from the UKSHS are presented in Appendix 9. Concentrations of Li in all industrial soils except one were well within the range of Li concentrations reported in world soils by Kabata-Pendias (2000).

Rubidium

Rb is a naturally occurring element found in rocks and soils. Geologically, Rb is associated with Li and is also mainly concentrated in acid igneous rocks and sedimentary aluminosilicates.

In soils, Rb is closely linked to potassium (K), though it is more strongly bound to silicate clay minerals than is K and therefore the Rb/K ratio continually decreases in soil-forming processes (Kabata-Pendias 2000). The Rb concentration of soils is largely related to its concentration in rocks, with the highest mean concentrations in soils developed on granites and gneisses (120 mg/kg) and in alluvial soils (100 mg/kg) (Kabata-Pendias, 2000).

Table 4.51 lists the concentration ranges of Rb found in different soils. The lowest Rb concentrations were reported by Shacklette and Boerngen (1984) for sandy and organic soils (30–50 mg/kg) and by Markert and Lieth (1987) for peat bogs (1–10 mg/kg). Reference soils from the USA and China had mean concentrations of 86 mg/kg and 106 mg/kg respectively (Govindaraju 1994). Organic matter and micaceous clay minerals increase the adsorption capacity of soils for Rb.

Table 4.51 – Range of Rb concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Soils from USA	69–1,141	86	–
Govindaraju (1994)	Soils from China	15–140	106	–
Kabata-Pendias (2000)	Soils from USA	<20–210	–	–
Markert and Lieth (1987)	Peat bogs	1–10	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<0.9–207	67	62
Shacklette and Boerngen (1984)	Sandy and organic soils	30–50	–	–

[1] HF extractable Rb in 750 topsoils in the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Rb in all industrial soils were well within the range of Rb concentrations reported in USA soils by Kabata-Pendias (2000). Apart from the soil at a steel works in Wales, all the Rb concentrations in the UK industrial soils were lower than the mean for Baltic soils (but a different extractant was used).

The few rural and urban soils examined showed Rb concentrations within the ranges reported by both Kabata-Pendias (2000) and Shacklette and Boerngen (1984).

Caesium

Cs is a naturally occurring element found in rocks and soils. Cs is concentrated mainly in acidic igneous rocks and in argillic sediments. There is a strong relationship between the Cs content of rocks and that of surface soils. The geochemical characteristics of Cs are similar to those of Rb, but Cs appears to be bound more strongly to aluminosilicate clay minerals. When Cs is mobilised through weathering, it is strongly adsorbed on clay minerals.

In Canadian soils, Koons and Helmke (1978) found a range of 0.3–5.1 mg/kg (Table 4.52). Govindaraju (1994) reported mean Cs concentrations in reference soils from the USA and China of 3.03 mg/kg and 9.31 mg/kg respectively.

Table 4.52 – Range of Cs concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Soils from USA	0.41–5.07	3.03	–
Govindaraju (1994)	Soils from China	2.7–21.4	9.31	–
Koons and Helmke (1978)	Canadian soils	0.3–5.1	–	–
Markert and Lieth (1987)	Peat bogs in Germany and Sweden	0.1–1	–	–
Reimann *et al.* (2003)[1]	Topsoils	<0.1–20	2.0	1.5

[1] HF extractable Cs in 750 topsoils in the Baltic Soil Survey

The ^{137}Cs isotope is of particular environmental interest because it is a by-product of atomic energy production. The geochemical characteristics of this isotope are broadly similar to those of non-radioactive Cs. Therefore, when ^{137}Cs is released into the atmosphere it becomes strongly adsorbed by clay minerals and soil organic matter.

The full data from the UKSHS are presented in Appendix 9. Concentrations of Cs in all industrial soils except two were well within the range of Cs concentrations reported in Canadian soils by Koons and Helmke (1978). The high Cs concentration at the power station site in England even exceeded the maximum Cs concentration found in the Baltic Soil Survey (and the Baltic survey used a more aggressive extraction than the UKSHS).

The few rural and urban soils examined showed Cs concentrations well within the range reported for Canadian soils.

Silver

Silver is a naturally occurring element found in rocks and soils. While the geochemical characteristics of Ag are similar to those of Cu, its concentration in rocks is around 1,000 times lower than Cu. Ag is easily released by weathering and is precipitated in alkaline conditions and in media containing sulphur compounds.

In soil, Ag can be present as Ag^+ salts as well as complex anions (e.g. $AgCl_2^-$, $Ag(S_2O_3)_2^{3-}$, $Ag(SO_4)_2^{3-}$). Ag is immobile in soils in conditions where pH >4. Humic compounds adsorb and complex with Ag^+, leading to an enrichment of Ag in surface soils.

Reviews of Ag in soils by Smith and Carson (1977a) and by Mukherjee (1997) indicated that the common concentration range in soil is 0.03–0.4 mg/kg, while Bowen (1979) reported a range in world soils to be 0.01–8 mg/kg (Table 4.53). Presant (1971) reported a range in Canadian soils to be 0.2–3.2 mg/kg, while the average Ag concentration reported in a British soil sample was 0.4 mg/kg (Ure and Bacon 1978). Ag concentrations in soils near to a mining site in south-west England were reported by Davies and Ginnever (1979) to be as high as 44 mg/kg. Jones *et al* (1986) calculated that background Ag levels are <0.1 mg/kg while soils contaminated by past mining activities in Wales contained up to 9 mg/kg. Soils rich in organic matter were reported to have Ag concentrations in the range 2–5 mg/kg (Shacklette and Boerngen 1984).

Table 4.53 – Range of Ag concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Bowen (1979)	General range worldwide	0.01–8	–	–
Davies and Ginnever (1979)	Mining sites (Great Britain)	<44	–	–
Edwards *et al.*(1995)[1]	–	<0.01–5	–	–
Jones *et al* (1986)	Soils in Wales contaminated by mining	Up to 9	–	–
Lis and Pasieczna (1995)	Soils in Poland	<1	–	–
Mukherjee (1997)	Soils in Finland	Up to 4	–	–
Presant (1971)	Canadian soils	0.2–3.2	–	–
Reimann *et al.* (2003)[2]	Topsoils	<1–1.04	<1	<1
Shacklette and Boerngen (1984)	Soils rich in organic matter	2–5	–	–
Smith and Carson (1977a)	General range worldwide	0.03–0.09	–	–
Ure and Bacon (1978)	British soils	–	0.4	–

[1] Also mentioned a range of up to 960 mg/kg in sewage sludges.
[2] Aqua regia extractable Ag in 750 topsoils in the Baltic Soil survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Ag in all industrial soils, except one chemical site in England, were well within the range of Ag concentrations reported in Canadian soils by Presant (1971) and lower than the maximum reported by Davies and Ginnever (1979) for mining sites in Great Britain. The soil Ag concentration at the majority of industrial sites was below the average concentration reported for British soils by Ure and Bacon (1978).

The few rural and urban soils examined showed Ag concentrations to be well within the range reported for Canadian soils and below the average reported for British soils (Ure and Bacon 1978).

4.4.2 Group II elements (Be, Sr, Ba)

The trace elements of Group II belong to the group of alkaline earths and behave very similarly to Ca and Mg. Be, Sr and Ba favour co-ordination with oxygen donors and do not usually form complex ionic species.

The common characteristic of these alkali earths is their association with the carbon cycle. The processes of solution and precipitation of carbonates strongly control the behaviour of these metals in the terrestrial environment.

Beryllium

Be is a naturally occurring element mainly found in acid igneous rocks, and in argillic sediments and shales. Be can also enter soils from the combustion of coal, the use of rocket fuels and the manufacture of corrosion-resistant alloys.

Be occurs in soils as Be^{2+} but can also form complex ions such as $(BeO_2)^{2-}$, $(Be_2O_3)^{2-}$, $(BeO_4)^{6-}$ and $(Be_2O)^{2+}$, as well as $Be(OH)CO_3^-$ and $Be(CO_3)_2^{2-}$. Organic substances bind Be readily and Be accumulates in organic soil horizons. Be^{2+} may be substituted for other divalent cations and also for aluminium(III) (Al^{3+}) and it is strongly bound by montmorillonite clays. Be forms readily soluble salts such as $BeCl_2$ and $BeSO_4$, and thus can be readily available in a mobile form and be toxic to plants.

The range of Be concentrations in soils of the USA and Canada were reported as <1–15 mg/kg (Shacklette and Boerngen 1984) and 0.10–0.89 mg/kg (Frank *et al.* 1979) respectively (Table 4.54). An average of 2.7 mg/kg was reported by Ure and Bacon (1978) for British soils. Soil Be concentrations were reported to range from 15–50 mg/kg in the vicinity of smelters and coal-fired power stations in Poland (Padzik and Wlodek 1979).

Table 4.54 – Range of Be concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Alloway *et al.* (1998)[1]	Soils in England and Wales	0.47–6.21	2.22	2.33
Asami (1988)	Unpolluted surface soils of Japan	0.27–1.95	1.17	–
Bhat and Pillai (1997)	Indian soils	0.33–0.77	0.48	–
Frank *et al.* (1979)	Canadian arable soils	0.10–0.89	–	–
Gough *et al.* (1988)	US soil (Alaska)			
Govindaraju (1994)	World soils	1.4–4.4	–	–
Kabata-Pendias (2000)	World surface soils	0.10–5.50	–	–
Kabata-Pendias and Pendias (1999)	Soils in Poland	<1–5	–	–
Padzik and Wlodek (1979)	Soils near Polish power station/smelter	15–50	–	–
Reimann *et al.* (2003)[2]	Baltic topsoils	<0.5–3.92	1.2	1.17
Ryglewicz (1988)	Soils of Czech Republic	4.01–4.55	4.28	–
Shacklette and Boerngen (1984)	US soils	<1–15[3]	–	–
Ure and Bacon (1978)	British soil	2.7	–	–

[1] 34 soils at sites remote from obvious sources of pollution
[2] HF extractable Be in 750 topsoils in the Baltic Soil Survey
[3] Highest concentrations in clay textured soils

The full data from the UKSHS are presented in Appendix 9. Concentrations of Be in all industrial soils were well within the range of Be concentrations reported in USA soils by Shacklette and Boerngen (1984) and significantly lower than the range of concentrations reported around power stations in Poland by Padzik and Wlodek (1979). The soil Be concentration at the majority of industrial sites was below the average concentration reported for British soils by Ure and Bacon (1978).

The few rural and urban soils examined showed Be concentrations well within the range reported for USA soils and also well below the average reported for British soils (Ure and Bacon 1978).

The UKSHS data all fall within the ranges reported by Alloway *et al.* (1998) and by Reimann *et al.* (2003).

Strontium

Sr is a relatively common, naturally occurring element mainly found in igneous rocks and in carbonate sediments. The geochemical and biochemical characteristics of Sr are similar to those of Ca.

The concentration of Sr in soil is mainly determined by the Sr content of the parent rock. Sr is easily mobilised during weathering, especially under oxidising and acidic soil conditions. Mobilised Sr is then fixed in clay minerals, bound strongly by organic matter or is precipitated as biogenic carbonates in invertebrate shell material. In mobile form, Sr mainly occurs as Sr^{2+} ions. In acid soils, Sr can be rapidly leached down the soil profile.

In the USA, mean Sr concentrations in topsoils were reported by Kabata-Pendias (2000) to range from 110–445 mg/kg, with the mean Sr concentration for worldwide soils of 87–210 mg/kg, and by Shacklette and Boerngen (1984) to range from 5–1,000 mg/kg (Table 4.55). Reference soils from China were reported to have Sr concentrations in the range 26–150 mg/kg. An average Sr concentration in British soils was given by Ure and Bacon (1978) as 261 mg/kg.

Table 4.55 – Range of Sr concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Reference soils from China	26–150	–	–
Kabata-Pendias (2000)	American topsoils	–	110–445	–
Kabata-Pendias (2000)	World soils	–	87–210	–
Kabata-Pendias and Pendias (1999)	Surface mineral soils in Poland	–	10–24	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<1.0–655	–	–
Shacklette and Boerngen (1984)	USA soils	5–1,000	23.0	15.0
Ure and Bacon (1978)	Great Britain average	261	–	–

[1] Aqua regia extractable Sr in 750 topsoils in the Baltic Soil Survey

The ^{90}Sr isotope is produced in many nuclear processes and is considered to be one of the most biologically hazardous radioactive elements for humans. ^{90}Sr is easily mobile in light (coarse textured) soils and is readily taken up by plants.

The full data from the UKSHS are presented in Appendix 9. Concentrations of Sr in all industrial soils were well within the range of Sr concentrations reported in American topsoils by Kabata-Pendias (2000). The Sr concentrations in the UKSHS samples were also all within the range reported by Reimann *et al.* (2003).

The few rural and urban soils examined showed low Sr concentrations. These were much lower than the range reported for USA soils and significantly below the average reported for British soils (Ure and Bacon 1978).

Barium

Ba is a relatively common, naturally occurring element mainly found in acid igneous rocks. Ba released by weathering is not very mobile because it is easily precipitated as the sulphate and carbonate, and it is strongly adsorbed by clays.

Kabata-Pendias (2000) reviewed soil data from around the world and reported that average soil Ba concentrations range from 19–2,368 mg/kg, with a range in topsoils of the USA of 10–2,000 mg/kg (Table 4.56). Ure and Bacon (1978) reported an average Ba concentration of 672 mg/kg for British soils.

Table 4.56 – Range of Ba concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Alloway *et al.* (1998)[1]	Topsoils	32–556	117.0	82
Govindaraju (1994)	Reference soils from USA	290–2,240	–	–
Govindaraju (1994)	Reference soils from China	180–1,210	–	–
Kabata-Pendias (2000)	World soils	19–2,368	–	–
Reimann *et al.* (2003)[2]	Baltic topsoils	3.6–311	55	46.0
Shacklette and Boerngen (1984)	USA soils	10–2,000	–	–
Ure and Bacon (1978)	Great Britain average	672	–	–

[1] Topsoils at 34 sites in England and Wales remote from obvious sources of pollution

[2] Aqua regia extractable Ba in 750 topsoils in the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Ba in all industrial soils were well within the range of Ba concentrations reported for world soils generally by Kabata-Pendias (2000) and the majority of the industrial soils had Ba concentrations within the range reported by Alloway *et al.* (1998). All except two sites had lower than the average Ba concentration (872 mg/kg) reported by Ure and Bacon (1978) in British soil.

The few rural soils examined also showed Ba concentrations mainly within the range reported by Alloway *et al.* (1998). They were also within the range reported by Reimann *et al.* (2003), but were significantly below the earlier data from Ure and Bacon (1978). The few urban soils examined showed Ba concentrations towards the lower end of the ranges reported previously for world soils.

4.4.3 Group III elements (B, Ga, Tl, Sc, Y)

Group III of the Periodic Table contains elements whose geochemical and biochemical characteristics are very different. Of this group, B is the only non-metal. Sc and Y are the rarest in their occurrence in the environment.

Boron

B is a naturally occurring element whose concentration in rocks varies widely.

In soils, it generally occurs as various boric acid derivatives and in combination with silicates. Mobilised B is retained by organic matters, clay minerals and sesquioxides, particularly the hydrated oxides of Al. B adsorption within soils is highly pH-dependent, with highest adsorption occurring at pH values >pH7. B can occur in relatively high concentrations in the soil solution, ranging from 67–3,000 µg/l (Kabata-Pendias 2000).

B is a micronutrient and it is considered to be the most mobile of the micronutrients in soil. It is typically leached down the soil profile under temperate wet conditions. For this reason, B is considered to be a potentially deficient nutrient in the majority of temperate topsoils.

The range of B concentrations in soils around the world was reported by Kabata-Pendias (2000) to be <1–467 mg/kg. US soils were reported by Shacklette and Boerngen (1984) to have B concentrations in the range 7–150 mg/kg (Table 4.57). In British soils, Ure and Bacon (1978) reported an average soil value of 4.7–21 mg/kg.

Table 4.57 – Range of B concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Kabata-Pendias (2000)	General range worldwide	<1–467	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<0.02–8.0	0.38	<0.2
Shacklette and Boerngen (1984)	USA soils	7–150	–	–
Ure and Bacon (1978)	Great Britain average	4.7–21	–	–

[1] Ammonium acetate extractable B in 750 topsoils in the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of B in all industrial, rural and urban soils were towards the lower end of the range of B concentrations reported generally for world soils by Kabata-Pendias (2000).

The few rural and urban soils examined showed B concentrations that were significantly higher than the range reported by Reimann *et al.* (2003) for Baltic topsoils. One rural soil from England and one urban soil from Scotland were found to have B concentrations higher than the average reported in an earlier study of British soils by Ure and Bacon (1978).

Gallium

Ga is a naturally occurring element present in rocks and soils. It may also enter the environment via the combustion of coal and from the processing of aluminium.

In soils, Ga is associated with oxides and sulphides and it has only limited mobility. Wedepohl (1969-74) reported the range of Ga concentrations in world soils to be 1–70 mg/kg (Table 4.58). The range in New Zealand soils was reported to be 16–48 mg/kg (Wells 1960) and in USA soils to be <5–70 mg/kg (Kabata-Pendias 2000). In British soils, Ure and Bacon (1978) reported the average Ga concentration to be 21 mg/kg. More recently, Reimann *et al.* (2003) reported the range in Baltic topsoils to be 0.4–27 mg/kg, while Govindaraju (1994) reported Ga levels in US soils to be 6.4–24.3 mg/kg and in soils from China as 10–40 mg/kg.

Table 4.58 – Range of Ga concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Asami *et al.* (1990)	Polluted and unpolluted soils in Japan	13–16	–	–
Govindaraju (1994)	Reference soils from the USA	6.4–24.3	–	–
Govindaraju (1994)	Reference soils from China	10–40	–	–
Kabata-Pendias (2000)	USA soils	<5–70	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	0.4–27	11.0	11.0
Ure and Bacon (1978)	Great Britain average	21	–	–
Wedepohl (1969-74)	World soils	1–70	28	–
Wells (1960)	New Zealand soils	16–48	–	–

[1] HF extractable Ga in 750 topsoils in the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Ga in all industrial soils except one were well within the range of Ga concentrations reported for world soils generally by Kabata-Pendias (2000). All except three further sites had concentrations lower than the average Ga concentration (21 mg/kg) reported by Ure and Bacon (1978) in British soil.

The few rural and urban soils examined showed Ga concentrations within the range reported recently for Baltic topsoils by Reimann *et al.* (2003) and were much lower than the earlier average reported for British soils by Ure and Bacon (1978).

Thallium

Tl is a naturally occurring element present in rocks and soils. It may also enter the environment via combustion of coal and the smelting of heavy metals. Tl is readily mobilised during weathering and is fixed in soils on clay minerals and by Mn and Fe oxides.

Smith and Carson (1977b) reported the range of Tl concentrations in USA soils to be 0.02–2.8 mg/kg (Table 4.59). In Canadian garden soils, the range was 0.17–0.22 mg/kg (Chattopadhyay and Jervis 1974). In British soils, Ure and Bacon (1978) reported an average Tl concentration of 0.27 mg/kg. Govindaraju (1994) reported Tl concentrations of 0.18–0.64 mg/kg in US soils and concentrations of 0.21–2.4 mg/kg in soils from China.

The full data from the UKSHS are presented in Appendix 9. Concentrations of Tl in all industrial soils were well within the range of Tl concentrations reported for soils in the USA by Smith and Carson (1977b).

Table 4.59 – Range of Tl concentrations reported in soils worldwide (mg/kg)

Reference	**Soil type**	**Range**	**Mean**	**Median**
Chattopadhyay and Jervis (1974)	Canadian garden soils	0.17–0.22	–	–
Edwards *et al.* (1995)	General	0.03–10	–	–
Govindaraju (1994)	Reference soils from the USA	0.18–0.64	0.41	–
Govindaraju (1994)	Reference soils from China	0.21–2.4	0.98	–
Logan (1985)	General	0.03–0.99	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<0.1–2.5	0.44	0.38
Smith and Carson (1977b)	USA soils	0.02–2.8	–	–
Smith and Carson (1977b)	Soils over sphalerite veins	Up to 5 ppm	–	–
Ure and Bacon (1978)	Great Britain average	0.27	–	–

[1] HF extractable Tl in 750 topsoils in the Baltic Soil Survey

The few rural and urban soils examined showed low Tl concentrations, well within the ranges reported for soils in the USA (Smith and Carson 1977b) and in the Baltic (Reimann *et al.* 2003), with only one rural soil in Scotland having a concentration higher than the average reported previously for British soils (Ure and Bacon 1978).

Scandium

Sc is a naturally occurring element present in rocks and soils.

In soil, Sc shows an affinity for complexing with phosphates, sulphates, carbonates, fluorides and amines. The range of Sc concentrations in surface soils is reported to range from 2.9–17 mg/kg (Laul *et al.* 1979), 0.5–46.4 mg/kg (Kabata-Pendias 2000) and 0.5–50 mg/kg (Horovitz 2000) (Table 4.60). Reimann *et al.* (2003) reported a range of 0.64–27 mg/kg in Baltic topsoils. Govindaraju (1994) reported Sc concentrations of 5–18 mg/kg in US soils and 5–28 mg/kg in soils from China. In British soils, the average Sc concentration was reported previously to be 12.7 mg/kg (Ure and Bacon 1978).

Table 4.60 – Range of Sc concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Reference soils from the USA	5–18	11	–
Govindaraju (1994)	Reference soils from China	5–28	15	–
Horovitz (2000)[1]	General	0.5–50	7	–
Kabata-Pendias (2000)	General range worldwide	0.5–46.4	–	–
Kabata-Pendias (2000)	USA soils	<5–30	–	–
Laul *et al.* (1979)	World soils	2.9–17	–	–
Reimann *et al.* (2003)[2]	Baltic topsoils	0.64–27	7.1	6.0
Shtangeeva (2005a)	Urban soils of St Petersburg, Russia	3.3–5.8	–	–
Ure and Bacon (1978)	Great Britain average	12.7	–	–

[1] Naturally occurring Sc in soil
[2] HF extractable Sc in 750 topsoils in the Baltic Soil survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Sc in the industrial soils were either at the low end of, or below, the ranges of Sc concentrations reported for soils worldwide and in the USA by Kabata-Pendias (2000). All soils from every industry studied had Sc concentrations lower than the average (12.7 mg/kg) reported by Ure and Bacon (1978) in British soils.

The few rural and urban soils examined showed low Sc concentrations at the low end of, or below, the ranges reported for soils in the Baltic, in Russia in the USA and elsewhere and lower than the average reported previously for British soils (Ure and Bacon 1978).

Yttrium

Y is a naturally occurring element present in rocks and soils. It occurs most frequently in soils as the phosphate, and as mixed oxides and complex silicates.

Kabata-Pendias (2000) reported the range of Y in US soils to be <10–150 mg/kg (Table 4.61). Erdman *et al*. (1976) showed that cultivated soils in the USA had lower concentrations of Y than uncultivated (15 and 23 mg/kg respectively). Gough *et al.* (1988) reported Y concentrations of <4–100 mg/kg in soils from Alaska. Govindaraju (1994) reported Y concentrations of 16–40 mg/kg in soils from the USA and 11–39 mg/kg in soils from China. In British soils, Ure and Bacon (1978) reported an average of 22 mg/kg.

Table 4.61 – Range of Y concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Erdman *et al*. (1976)	Cultivated soils (average)	–	15	–
Gough *et al.* (1988)	Soils of Alaska	<4–100	14	–
Govindaraju (1994)	Reference soils from the USA	16–40	24	–
Govindaraju (1994)	Reference soils from China	11–39	22	–
Kabata-Pendias (2000)	Uncultivated soils	–	23	–
Kabata-Pendias (2000)	USA soils	<10–150	25	–
Reimann *et al.* (2003)[1]	Baltic topsoils	1.4–56	14	13
Ure and Bacon (1978)	Great Britain	–	22	–

[1] HF extractable Y in 750 topsoils in the Baltic Soil survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Y in all industrial soils were within the range of Y concentrations reported for soils in the USA by Kabata-Pendias

(2000). Soils from all industries except three had Y concentrations lower than the average (22.0 mg/kg) reported by Ure and Bacon (1978) in British soils.

The few rural and urban soils examined showed low Y concentrations, at the low end of the ranges reported for soils in the Baltic and in the USA, and significantly lower than the average reported previously for British soils (Ure and Bacon 1978).

4.4.4 Lanthanides (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)

Lanthanides are known as the rare earth elements. They show an affinity for oxygen and often several rare earths may be present together in soils as mixed phosphate minerals. There are two main sub-groups of these elements:

- the first sub-group from La to Gd are more basic and soluble;
- the second sub-group from Tb to Lu are less basic and less soluble.

Table 4.62 presents summarised data on lanthanides in soils. More recent data from the Baltic Soil Survey (Reimann *et al.* 2003) are presented in Table 4.63. These data indicate that the most abundant elements are La, Ce and Nd. Elevated concentrations of La, Ce, Sm, Eu and Tb have been found in the air of urban and industrial areas. These elements are known to be released into the environment from coal burning and nuclear energy materials processing.

Table 4.62 – Range of lanthanide concentrations reported in soils worldwide (mg/kg)

Element	**Ure and Bacon (1978) (British soils)**	**Bowen (1979) (world soils)**	**Laul *et al.* (1979) (World soils)**	**Kabata–Pendias (2000) (world soils)**		**Govindaraju (1994) (world soils)**	**Zhu *et al.* (1997) (Chinese soils)**	**Yoshida *et al.* (1998) (Japanese soils)**
				Range	**Mean**			
La	33.5	40	29.5	<2–120	26.1	35.1	35.2	8.53–31.4
Ce	48.5	50	29.5	<5–225	48.7	71.1	97.4	15.8–64.4
Pr	7.7	7.5	6.7	1.4–15	7.6	5.4	8.4	1.84–5.01
Nd	33.0	35	27.9	<4–120	19.5	30.6	29.3	7.69–28.6
Sm	6.1	4.5	5.1	1.89–22.6	4.8	6.7	5.5	1.75–3.98
Eu	1.9	1	1	0.37–7.66	1.23	1.2	0.8	0.44–1.43
Gd	3.0	4	4.7	0.7–15	6.03	3.2	4.8	1.77–5.54
Tb	0.63	0.7	0.7	0.11–1.7	0.71	0.85	0.58	0.27–0.82
Dy	3.8	5	–	0.8–12	3.65	4.3	2.9	1.68–4.67
Ho	0.38	0.6	1.1	0.19–2.0	1.08	0.96	0.51	0.36–0.95
Er	2.0	2	2.8	0.26–4.8	1.58	2.6	1.4	1.08–2.72
Tm	0.16	0.6	0.4	0.38–0.80	0.46	0.34	0.19	0.16–0.40
Yb	2.3	3	3.1	0.81–6	2.06	2.4	1.1	1.11–2.64
Lu	0.34	0.4	0.3	0.10–0.72	0.34	0.39	0.16	0.16–0.40

Table 4.63 – Range of lanthanide concentrations reported in Baltic Soil Survey[1] (mg/kg)

Element	Minimum	Maximum	Mean	Median
La	2.3	113	20	33
Ce	3.7	167	42	37
Pr	0.4	24	4.8	4.3
Nd	1.7	86	18	16
Sm	<0.2	15	3.4	3.0
Eu	0.06	2.3	0.68	0.64
Gd	0.24	13	3.1	2.8
Tb	<0.05	2.0	0.46	0.42
Dy	0.24	10	2.5	2.3
Ho	0.05	2.0	0.48	0.44
Er	<0.15	5.0	1.4	1.3
Tm	<0.05	1.0	0.2	0.19
Yb	–	–	–	–
Lu	<0.05	1.0	0.2	0.19

[1] HF extractable lanthanides in the 750 topsoil samples of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9.

Of the lanthanides, only for La were there a large number of incidences where the concentration in UK industrial soils was higher than the average lanthanide concentration (33.5 mg/kg La) reported previously by Ure and Bacon (1978) for British soils. The mean La concentration reported for Baltic soils was lower than the average value given by Ure and Bacon (1978) for British soils, but the maximum La content found in the Baltic soils is far greater than the maximum value reported from the literature by Kabata-Pendias (2000). The highest value for La found in the UKSHS (92 mg/kg) is still within the range found in the Baltic soils.

Although the majority of industrial sites have soil Ce concentrations well below the ranges reported for world soils and below the average reported for British soils, samples from two sites in Wales showed Ce concentrations that are well above the ranges of concentrations which have been reported for world soils.

One mineral industry site showed relatively elevated concentrations of many of the lanthanides scanned. In addition, there were a few locations where the concentration of a single lanthanide element exceeds ranges generally reported for world soils.

4.4.5 Actinides (Th, U)

U and Th are the only naturally occurring actinides in rocks and soils. U and Th are also introduced into the environment from the burning of fossil fuels and from the manufacture of phosphate fertilisers. During weathering, U and Th are easily mobilised to form hydrates of UO_2^{2+} and Th^{4+}, which are responsible for the solubility of these metals over a broad range of soil pH. However, the mobility of U and Th may be limited due to both the formation of slightly soluble precipitates (e.g. phosphates and oxides) and adsorption onto clay minerals and organic matter.

The range of Th and U concentrations in soils worldwide is reported by Kabata-Pendias (2000) as 0.4–76 mg/kg and 0.1–45 mg/kg respectively (Table 4.64). Kabata-Pendias (2000) also gave a worldwide mean for Th of 3.4–13.4 mg/kg and for U of 0.79–11 mg/kg. In the UK, Ure and Bacon (1978) reported average soil concentrations of 10.5 mg/kg Th and 2.6 mg/kg U. Mean contents of Th and U in Polish surface soils (24–40 cm) are reported to be 3.29 mg/kg Th and 1.36 mg/kg U (Strzelecki *et al.* 1994). Surface forest soils in Japan are reported to contain Th concentrations of 2.56–12.4 mg/kg and 0.024–1.15 mg/kg (Yoshida and Muramatsu 1997).

Table 4.64 – Range of actinide concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Th			U		
		Range	Mean	Median	Range	Mean	Median
Kabata-Pendias (2000)	Surface soils of different countries	0.4–76	3.4–13.4	–	0.10–45	0.79–11.00	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<0.4–20	5.5	4.9	<0.1–56	2.0	1.4
Shtangeeva (2005b)	General	2.56–18.5	–	–	–	–	–
Shtangeeva (2005b)	North-west Russia	6–8.7	–	–	–	–	–
Strzelecki *et al.* (1994)	Surface soils of Poland	–	3.29	–	–	1.36	–
Ure and Bacon (1978)	Great Britain	–	10.5	–	–	2.6	–
Yoshida and Muramatsu (1997)[2]	Forest soils in Japan	2.56–12.4	–	–	0.024–1.15	–	–

[1] HF extractable Th and U in the 750 topsoils of the Baltic Soil Survey
[2] Surface soils in Japanese forests

The full data from the UKSHS are presented in Appendix 9.

Concentrations of Th in all industrial soils were either just below or well within the range reported for soils worldwide by Kabata-Pendias (2000) and were also just below or well within the range reported by Shtangeeva (2005b). Kabata-Pendias (2000) noted that fossil fuel combustion and phosphate fertiliser manufacture were significant sources of Th contamination in soils. Concentrations of U in all industrial soils are well within the general range reported by Kabata-Pendias (2000). All industrial soils except one had Th concentrations lower than the average (10.5 mg/kg) reported by Ure and Bacon (1978) in British soils. All but two had U concentrations lower than the average (2.6 mg/kg) reported by Ure and Bacon (1978) in British soils

The few rural soils examined showed much lower Th concentrations than the ranges reported by Kabata-Pendias (2000) and by Shtangeeva (2005b) for soils worldwide, and lower than the average reported for British soils (Ure and Bacon 1978). However, Th concentrations in the UKSHS for both rural and urban soils were towards the low end of the Baltic soil concentrations reported by Reimann *et al.* (2003). The UKSHS urban Th concentrations in Scotland were just below the levels for general soils reported by Kabata-Pendias (2000) and by Shtangeeva (2005b). The UKSHS rural soil samples had U concentrations towards the low end of the ranges reported by Kabata-Pendias (2000) and by Reimann *et al.* (2003), and much lower than the average level given previously by Ure and Bacon (1978). The UKSHS urban soil samples in Scotland gave the same U concentration as the mean concentration in Baltic topsoils reported by Reimann *et al.* (2003). They were similar to the concentration level reported previously by Ure and Bacon (1978) but at the low end of the ranges reported by Kabata-Pendias (2000) and by Shtangeeva (2005b).

Other elements of the actinides, the transuranic radionuclides, are isotopes released from the nuclear power industry. These include plutonium (Pu), americium (Am), curium (Cm) and neptunium (Np).

4.4.6 Group IV elements (Ge Zr)

Germanium

Ge is a naturally occurring element present in rocks and soils. During weathering, Ge is partly mobilised but is readily fixed to clay minerals, to Fe oxides and to soil organic matter.

Govindaraju (1994) reported a mean Ge concentration of 1.6 mg/kg in soils from China and Reiman *et al.* (2003) reported a mean Ge concentration of 3.1 mg/kg in Baltic topsoils. Shacklette and Boerngen (1984) reported the range of Ge in soils of the USA to be <0.1–2.1 mg/kg (Table 4.65).

Table 4.65 – Range of Ge concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Reference soils from China	1.2–3.2	1.6	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<0.1–7.5	3.1	3.0
Shacklette and Boerngen (1984)	USA soils	<0.1–2.1	–	–

[1]HF extractable Ge in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Ge in all industrial soils were well within the range of Ge concentrations reported for soils in the USA by Shacklette and Boerngen (1984).

The few rural and urban soils examined all showed low Ge concentrations in the range ND–0.1 mg/kg. All the Ge concentrations in the UKSHS were well below the median value for the Baltic soils (although the extraction procedures differ).

Zirconium

Zr is a naturally occurring element present in rocks and soils. The widely distributed Zr mineral, zircon, is highly resistant to weathering. Zr is only slightly mobile in soils.

Like Ti, Zr has been used as an index element in soil studies. Kabata-Pendias (2000) commented on the close relationship between Zr levels in the parent material and in soils, and reported that the average Zr content calculated for various soils of the USA was 224 mg/kg. Lower amounts of Zr were found in soils on glacial drift (mean 140 mg/kg) and higher amounts were found in residual soils from Zr-rich rocks (mean 305 mg/kg). Govindaraju (1994) gave Zr concentrations in reference soils from the USA in the range 184 mg/kg (Table 4.66).

Table 4.66 – Range of Zr concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Chattopadhyay and Jervis (1974)	Canadian garden soils	200–278	–	–
Govindaraju (1994)	Reference soils from the USA	184–760	279	–
Govindaraju (1994)	Reference soils from China	219–500	281	–
Kabata-Pendias (2000)	USA soils	–	224	–
Reimann *et al.* (2003)[1]	Baltic topsoils	1.1–255	72	66
Wells (1960)	New Zealand soils	330–850	–	–

[1]HF extractable Zr in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. The few rural and urban soils examined showed very much lower Zr concentrations than the ranges reported for soils elsewhere in the world. Concentrations of Zr in all UK industrial soils were very much lower than the mean Zr concentrations reported for soils in the USA (Govindaraju 1994, Kabata-Pendias 2000), Canada (Chattopadhyay and Jervis 1974), China (Govindaraju 1994) and in the Baltic Soil Survey (Reinmann *et al*. 2003).

The ICPMS scans for the UKSHS were carried out on aqua regia digests and the low UKSHS results could be the result of a bias due to incomplete extraction of the Zr from the soil. HF digestion, as used in the Baltic Soil Survey, would probably give better recoveries and thus higher results.

4.4.7 Group V elements (Sb, Bi, Nb)

Antimony

Sb is a naturally occurring element which is present in rocks and soils. Reactions of Sb during weathering are not well known but a relatively high mobility in the environment has been indicated (Kabata-Pendias 2000).

Sb concentrations in surface soils were reported by Kabata-Pendias (2000) to range from 0.05–4 mg/kg (Table 4.67). Jones *et al.* (1995) gave an overall range of Sb in soils from various countries as 0.3–9.5 mg/kg. Gavindaraju (1994) reported a mean Sb concentration of 2.4 mg/kg in US soils and a mean concentration of 13.6 mg/kg in soils from China. For British soils, Ure and Bacon (1978) reported an average Sb concentration of 0.56–1.3 mg/kg.

Like As, Sb may be associated with non-ferrous ores and it is likely to be a pollutant within releases from metal processing industries. Crecelius *et al*. (1974) reported elevated concentrations of Sb (up to 200 mg/kg) in soils around a Cu smelter.

Table 4.67 – Range of Sb concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Reference soils from the USA	0.11–14.0	2.4	–
Govindaraju (1994)	Reference soils from China	0.5–60	13.6	–
Jones *et al.* (1995)	World soils	0.3–9.5	–	–
Kabata-Pendias (2000)	World soils	0.05–4	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<10.0–<10	–	–
Reimann *et al.* (2003)[2]	Baltic topsoils	<1.0–3.2	0.27	0.24
Ure and Bacon (1978)	Great Britain average	0.56–1.3	–	–

[1] Aqua regia extractable Sb in the 750 topsoils of the Baltic Soil Survey

[2] HF extractable Sb in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Sb in some of the industrial soils sampled were significantly in excess of the top of the range reported for worldwide soil levels by Kabata-Pendias (2000).

The few rural and urban soils examined showed Sb concentrations which were within the range reported by Kabata-Pendias (2000) for soils worldwide and close to the range reported by Ure and Bacon (1978). The concentrations of Sb found in the UKSHS samples were generally much higher for the industrial soils than those found in the Baltic soils with an HF extraction. Very little Sb was detected in the Baltic agricultural soils using aqua regia extraction.

Bismuth

Bi is a naturally occurring element present in rocks and soils. During weathering, Bi is readily oxidised and it also forms carbonates such as the basic carbonate $[(BiO)_2CO_3]_2.H_2O$, which are relatively stable in a soil environment. The Bi concentration in topsoils is directly related to the concentration in the parent rock. Bi appears to be enriched in soil horizons containing Fe oxides and soil organic matter.

The range of Bi concentrations in Canadian garden soils was reported to be 1.33–1.52 mg/kg (Chattopadhyay and Jervis 1974), while Bowen (1979) reported a mean Bi concentration of 0.2 mg/kg in world soils (Table 4.68). Ure *et al*. (1979) reported a range of 0.13–0.42 mg/kg in Scottish soils. Govindaraju (1994) reported Bi concentrations of 0.03–0.69 mg/kg in reference soils of the USA and concentrations of 0.04–1.2 mg/kg in reference soils from China. Reimann *et al.* (2003) gave a mean concentration of 0.25 mg/kg for Baltic topsoils.

Table 4.68 – Range of Bi concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Bowen (1979)	World soils (average)	0.2	–	–
Chattopadhyay and Jervis (1974)	Canadian garden soils	1.33–1.52	–	–
Govindaraju (1994)	Reference soils from the USA	0.03–0.69	–	–
Govindaraju (1994)	Reference soils from China	0.04–1.2	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	0.0053–1.21	0.09	0.07
Ure *et al.* (1979)	Scottish soils	0.13–0.42	0.25	–

[1] Aqua regia extractable Bi in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Bi in soil at one chemical site in England were found to be significantly higher than the ranges reported elsewhere. In general, the Bi levels in soils from the UKSHS industrial sites were at the lower levels reported for Scottish soils by Ure (1979) rather than at the levels reported for soils in Canada by Chattopadhyay and Jervis (1974). The majority of the UKSHS soil samples had Bi concentrations within the range reported by Reimann *et al.* (2003) for Baltic soils.

The few rural and urban soils examined showed a range of Bi concentrations, with one rural site in Wales having a Bi concentration significantly higher than the range reported for British soils (Ure *et al.* 1979).

Niobium

Nb is a naturally occurring element that is present in rocks and soils. The pentavalent Nb compounds are relatively stable. Most Nb compounds are slightly soluble in both acid and alkaline media. The presence of organic complexing agents mobilises Nb.

Govindaraju (1994) reported Nb concentrations of 6.4–22.0 mg/kg in reference soils of the USA and Nb concentrations of 9.3–37.6 mg/kg in Chinese reference soils. Gough *et al.* (1988) found Nb concentrations in various soils of Alaska to range from <4 to 44 mg/kg. Reimann *et al.* (2003) reported a median value of 12.5 mg/kg in Lithuanian soils (Table 4.69). In the UK, Ure *et al.* (1979) reported a range of 31–300 mg/kg in Scottish soils, with an average Nb concentration for British soils of 24 mg/kg.

Table 4.69 – Range of Nb concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Gough *et al.* (1988)	Soils of Alaska	<4–44	8	–
Govindaraju (1994)	Reference soils of the USA	6.4–22.0	–	–
Govindaraju (1994)	Reference soils of China	9.3–37.6	–	–
Kabata-Pendias (2000)	USA soils	5–100	–	–
Kadunas *et al.* (1999)	Lithuanian soils	–	–	12.5
Reimann *et al.* (2003)[1]	Baltic topsoils	1.13–43	6.4	5.3
Ure and Bacon (1978)	Great Britain average	–	24	–
Ure *et al.* (1979)	Scottish soils	31–300	–	–

[1] HF extractable Nb in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Apart from one chemical site in Scotland, the concentrations of Nb in UKSHS industrial soils tended to be much lower than the bottom of the ranges reported by Govindaraju (1994). Nearly all the Nb concentrations in the UKSHS industrial soils were below the median value (in HF) for the Baltic soils (Reimann *et al.* 2003). The chemical industry site in Scotland referred to above had a much higher Nb content, but this fell within the range found in the Baltic soils. The Nb levels in UKSHS rural soils were below the range reported for Baltic soils. The Nb concentration in Scottish urban soil was at the bottom of the range reported for Baltic soils. However, the Baltic data are for the more aggressive HF digestion.

4.4.8 Group VI elements (Se, Mo, W)

Selenium

Se is a naturally occurring element present in rocks and soils. and it is often associated with sulphide minerals. Se also enters the atmosphere in emissions from the combustion of fossil fuels and from metal processing industries.

Se in soil tends to be adsorbed on clay particles, iron and manganese minerals, and organic matter. The chemical forms of Se present in soils are closely related to the oxidation–reduction potential and pH of the soil. Se weathered from rocks under alkaline and oxidising conditions forms selenates, and it is only in alkaline and well-oxidised soil conditions that soluble Se derivatives are formed, which are not readily fixed on clay minerals. pH-neutral soils tend to contain selenites. Selenites and selenates are produced by soil microorganisms from the less soluble forms of Se and, by being mobile in alkaline soils, they facilitate the uptake of Se by certain plants. Soil micro-organisms can also reduce selenites and probably selenates to elemental selenium. Biological methylation of Se occurs in soil, yielding volatile Se compounds. Soluble organoselenium compounds can be released through the decay of plants. In acid soils, Se is relatively immobile, due to the formation of stable compounds, and is not actively available to plants. Se is an essential element (micronutrient) for animals and humans, and it has been extensively investigated both with regard to toxicity and also deficiencies in humans and livestock.

The general range of Se concentrations in soils worldwide was reported by Kabata-Pendias 2000 to be 0.005–4.0 mg/kg, with a mean of 0.33 mg/kg (Table 4.70). Forest soils were reported to contain elevated amounts of Se (Borowska *et al.* 1994). Scottish soils on mafic rocks were reported to have Se concentrations of 0.02–0.36 mg/kg (Ure *et al.* 1979). In a report on human diseases associated with Se-deficient soils, Xu and Jiang (1985) compared the water-soluble Se content of soils in endemic areas of China (0.0002–0.002 mg/kg) with soluble Se levels in neighbouring non-endemic areas (0.001–0.011 mg/kg). For soils in the UK associated with Se toxicity in livestock, Williams and Thornton (1972) reported Se concentrations of 92–230 mg/kg. Other data on Se in soils can be found in Adriano (2001).

Table 4.70 – Range of Se concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Adriano (2001)	World soils	0.03–2.0	–	–
Adriano (2001)	UK seleniferous soils	0.9–91.4	–	–
Adriano (2001)	Normal UK soils	0.2–1.8	–	–
Adriano (2001)[1]	Soils of USA with alkaline pH	6–28	–	–
Borowska *et al.* (1994)	Forest soils of Poland	–	0.7	–
Kabata-Pendias (2000)	General range worldwide	0.005–4.0	0.33	–
Kabata-Pendias (2000)	Soils of the USA	0.005–4.0	–	–
Reimann *et al.* (2003)[2]	Baltic topsoils	0.015–7.6	0.19	0.14
Ure *et al.* (1979)	Scottish podsols	0.15–0.24	–	–
Ure *et al.* (1979)	Scottish soils on mafic rocks	0.02–0.36	0.20	–
Voland *et al.* (1987)	Soils of Germany	0.09–0.45	0.27	–
Williams and Thornton (1972)	Soils in the UK associated with Se toxicity in livestock	92–230	–	–
Xu and Jiang (1985)[3]	Chinese Se-deficient soils	0.0002–0.002	–	–
Xu and Jiang (1985)[4]	Chinese soils with higher Se levels	0.001–0.011	–	–

[1] Soils in the USA (with alkaline pH) that caused selenosis (Se toxicity) in livestock
[2] Aqua regia extractable Se from the 750 topsoils of the Baltic Soil Survey
[3] Chinese soils in areas associated with cardiomyopathy and tubular bone changes
[4] Chinese soils in neighbouring non-endemic areas

The full data from the UKSHS are presented in Appendix 9. Concentrations of Se in UK industrial soils varied widely, with soils at a chemical site in England and at an incinerator site in Wales exceeding the ranges of Se concentrations generally found in world soils (Kabata-Pendias 2000, Adriano 2001). Se concentrations in the majority of industrial soils were higher than the upper range of values reported by Ure *et al.* (1979) for different soils in Scotland.

The occurrence of some high Se concentrations indicates that there is possibly a risk of selenium toxicity in livestock grazing pastures near to sites with high Se concentrations. However, the uptake of Se is very pH-dependent and sulphur acts as an antagonist of Se reducing uptake. Any fallout of Se onto herbage is a possible route for causing selenium toxicity.

The few rural soils examined showed relatively high Se concentrations, outside the ranges reported by Ure *et al.* (1979) for Scottish soils.

Molybdenum

Mo is a naturally occurring element present in rocks and soils. Mining, smelting and processing of metals and oil refining may all release Mo into the atmosphere. Mo is an essential trace element (micronutrient) for plants. During weathering, Mo sulphides are slowly oxidised and yield mainly the MoO_4^{2-} anion, which dominates in neutral and moderately alkaline soils, and $HMoO_4^-$ which occurs in more acidic soil conditions. These mobile anions are easily co-precipitated by organic matter, $CaCO_3$ and by several cations such as Pb^{2+}, Cu^{2+}, Mn^{2+} and Ca^{2+}; they are also adsorbed by Fe, Mn and Al hydrated oxides. Which reactions occur depends on redox and pH conditions. Mo is least soluble in acid conditions, but becomes readily mobilised in alkaline conditions. Liming of acid soils is a common practice to increase Mo availability to plants.

Kabata-Pendias (2000) reported the range of Mo concentrations worldwide to be 0.13–17 mg/kg. For soils in the USA, a range of 0.8–3.3 mg/kg was reported by Kubota (1977) (Table 4.71). Govindaraju (1994) reported Mo concentrations of 1–2 mg/kg in reference soils of the USA and concentrations of 0.3–18 mg/kg in Chinese reference soils. A very high content of Mo, up to 24 mg/kg in the soils of British Columbia (Canada) was reported by Pieri *et al.* (1996). The median content of Mo in Lithuanian soils was reported to be 0.62 mg/kg (Kadunas *et al.* 1999). Koljonen (1992) reported a Mo concentration at the 90th percentile in Finnish soils of 1.5 mg/kg (HF extractable). In Scottish soils, Ure *et al*. (1978) reported a range of 1–5 mg/kg.

Localised high levels of Mo in soil may be due to industrial pollution. Schalscha *et al.* (1987) reported Mo concentrations of 22.2–38.2 mg/kg in surface soils surrounding a Mo processing plant in Chile. Some sewage sludges contain elevated concentrations of Mo (up to 50 mg/kg) and may enrich the total Mo of soils to which sewage sludges have been added, as well as increasing the solubility of soil Mo (Lahann 1976). The fallout or application of flyash from coal-fired power stations also raises the Mo concentrations in soils.

Table 4.71 – Range of Mo concentrations reported in soils worldwide (mg/kg)

Reference	**Soil type**	**Range**	**Mean**	**Median**
Govindaraju (1994)	Reference soils of the USA	1–2	–	–
Govindaraju (1994)	Reference soils of China	0.3–0.18	–	–
Kabata-Pendias (2000)	World soils	0.13–17	–	–
Kadunas *et al.* (1999)	Lithuanian soils	–	–	0.62
Kubota (1977)	USA soils	0.8–3.3	2	–
Pieri *et al* (1996)	Soils of British Columbia (Canada)	Up to 24	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<3–74	<3	<3
Ure et al. (1978)	Scottish soils	1–5	1.2	–

[1] Aqua regia extractable Mo in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Mo in soil samples from most of the UKSHS industrial sites were within the range of Mo concentrations generally found in world soils (Kabata-Pendias 2000).

The few rural and urban soils examined show low Mo concentrations close to the bottom of the ranges reported by Ure *et al.* (1979) for Scottish soils and those reported by Reimann *et al.* (2003) for Baltic topsoils.

Elevated Mo concentrations (usually >2.0 mg/kg or possibly lower – depending on pH) in pasture soils can lead to Mo-induced Cu deficiency in grazing livestock.

As with Se, the high Mo concentrations at some of the UKSHS industrial sites could possibly indicate a potential risk of molybdenosis in any livestock grazing pastures contaminated by fallout from industrial operations emitting significant amounts of Mo.

Tungsten

W is a naturally occurring element present in rocks and soils. W may also enter the environment from mining and metal processing industries. All W minerals are only slightly soluble and are not generally mobile in soils. W is present in soils as WO_4^{2-} and in various complex compounds.

Govindaraju (1994) reported concentrations of 0.5–5 mg/kg in reference soils of the USA and the broad range of 0.95–85.5 mg/kg in Chinese reference soils. The soils of Finland contained 2.23 mg/kg at the 90th percentile range (Koljonen 1992). The concentration of W in two soils in the USA was reported by Furr *et al*. (1980) to be 1.2–2.5 mg/kg (Table 4.72). Ure *et al*. (1979) reported a range of 0.68–2.7 mg/kg for Scottish soils.

Table 4.72 – Range of W concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Furr *et al*. (1980)	USA soils	1.2–2.5	–	–
Govindaraju (1994)	Reference soils of the USA	0.5–5	–	–
Govindaraju (1994)	Reference soils of China	0.95–85.5	–	–
Reimann *et al.* (2003)[1]	Baltic topsoils	<5–40	<5	<5
Ure *et al*. (1979)	Scottish soils	0.68–2.7	–	–

[1] HF extractable W in the 750 topsoils from the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of W in soils at two steel sites and at one incinerator site were found to be significantly higher than the range of W concentrations reported for soils in the USA (Furr *et al.* 1980) and Scotland (Ure *et al.* 1978). Many of the soils at the other industrial sites were found to have W concentrations below these ranges.

The few rural and urban soils examined showed lower W concentrations than the range reported for Scottish soils (Ure *et al.* 1978).

The UKSHS concentrations of W in soils were all within the range found in the Baltic soils (Reimann *et al.* 2003).

4.4.9 Group VIII elements (Co)

Cobalt

Co is a naturally occurring element present in rocks and soils, with higher concentrations present in ultramafic rocks (100–220 mg/kg) compared with acidic rocks (1–15 mg/kg). Co is an essential trace element (micronutrient) for animals, which synthesise it into the Vitamin B12 required by humans. Co is present in soils in two oxidation states, as Co^{2+} and Co^{3+}. During weathering, Co is relatively mobile under acidic oxidising soil conditions, but is strongly adsorbed by Fe and Mn oxides and by clay minerals. The adsorption of Co by Mn oxides increases with pH. Montmorillonite and illite clay minerals are important in the exchange of Co in soils. Organic chelates of Co are mobile in soil, easily translocated and are available to plants, especially at higher pH and in freely draining soils.

Soil Co concentration is dependent on the parent rock materials, with the highest concentrations in soils developed on ultramafic soils. The grand mean Co concentration for worldwide soils is reported to be 7.9 mg/kg and for soils of the USA to be 8.2 mg/kg (Kabata-Pendias 2000). The normal range of Co in surface soils was stated by Kabata-Pendias (2000) to be 0.1–70 mg/kg, but much higher concentrations of 122 mg/kg in Australian ferralsols and 116 mg/kg in some Japanese soils have been reported. Govindaraju (1994) reported mean Co concentrations of 10 mg/kg in reference soils of the USA and 11.6 mg/kg in Chinese reference soils. The median value for the total Co concentration in Lithuanian soils was reported to be 3.4 mg/kg (Kadunas *et al.* 1999). For forest podzolic soils in Russia, the Co concentration was reported to be about 5.5 mg/kg. Ure *at al*. (1978) reported an average value of 17.7 mg/kg in Scottish soils.

Table 4.73 –Range of Co concentrations reported in soils worldwide (mg/kg)

Reference	Soil type	Range	Mean	Median
Govindaraju (1994)	Reference soils of the USA	5.5–29.9	10	–
Govindaraju (1994)	Reference soils of China	5.5–97	11.6	–
Kabata-Pendias (2000)	USA soils	0.3–17.0	–	–
Kabata-Pendias (2000)	Normal range for world soils	0.1–70	–	–
Kadunas *et al* (1999)	Lithuanian soils	–	–	3.4
Reimann *et al.* (2003)[1]	Baltic topsoils	<1.0–39	5.4	4.1
Ure *et al.* (1979)	Scottish soils	–	17.7	–

[1] Aqua regia extractable Co in the 750 topsoils of the Baltic Soil Survey

The full data from the UKSHS are presented in Appendix 9. Concentrations of Co in all except one of the industrial soils were within the range of Co concentrations reported by Kabata-Pendias (2000) for soils worldwide, and within the range of Co concentrations reported for the Baltic soils (Reimann *et al*. 2003). The Co concentrations in the UKSHS industrial soils tended to be high relative to the median concentration for the Baltic soils. The highest concentration was in a sample from a metals industry site.

The few rural and urban soils examined showed lower Co concentrations than the concentration reported for Scottish soils (Ure *et al*, 1979), but they were higher than the mean Co concentration reported for Baltic soils.

4.4.10 Conclusions on semi-quantitative scan of elements in soils from industrial sites

The ICPMS semi-quantitative scan of 37 little-studied elements provided some reassuring and some surprising results.

A general estimate of the relative accuracy of the semi-quantitative data is ±40 per cent. Reassuringly, there were very few elements that appeared to be present in concentrations considered to be high compared with those found in soils worldwide.

However, the measured concentrations of Zr were much lower than levels reported previously and it is thought that this might indicate a bias due to incomplete extraction of Zr by the aqua regia methodology used during preparation of the samples for ICPMS scans. Better recoveries and higher results may have been achievable with HF extraction.

Seven elements (Ce, Gd, Sb, Bi, Se, Mo and W) were found to be present at two or more UK industrial soils at concentrations greater than the generally reported range of concentrations in world soils. Of these, exceedances of the final five elements in particular (Sb, Bi, Se, Mo and W) are of note since they were spread across several industrial types.

In addition, Li, Ag, Ga, La, Tb, Tm, Yb and Lu were found to be present in only one UK industrial soil at concentrations greater than the generally reported range of concentrations in world soils

These results indicate that a more detailed study of certain elements – particularly Sb, Bi, Se, Mo and W in industrial soils and Se in rural soils – may be justified.

Looking at individual industrial sites, there are several locations in which soil concentrations of elements exceed, for one or more of these elements, the generally reported worldwide soil concentrations (Table 4.74).

Table 4.74 – Number of incidences where soil concentrations of elements exceed generally reported soil concentrations

Industry	Country	No. of exceedances	Elements that exceeded
Chemical	England	4	Ag, Sb, Bi, Se
	Wales	3	Ce, Sb, Se
General	N. Ireland	1	Se
Incinerator sites	England	2	Sb, Se
	Scotland	1	Bi
	Wales	6	Ce, Sb, Bi, Se, Mo, W
Mineral	England	3	La, Gd, Tb
	N. Ireland	1	Yb
	Scotland	3	Li, Sb, Mo
Non-ferrous metals	England	1	Sb
	Wales	4	Sb, Bi, Se, W
Oil refinery	Scotland	1	Ga
Power station	England	1	Sb
	Scotland	1	Tm
	Wales	2	Gd, Se
Steel	England	4	Lu, Sb, Mo, W
	Wales	4	Sb, Bi, Se, W
Tar/bitumen	England	1	Gd

Table 4.74 indicates that, for several industrial sites included in the UKSHS, further more detailed investigations of soil concentrations of these little known elements may be justified. In particular, there should be further study at the incinerator site in Wales where the soil concentration of six elements exceeded generally reported soil concentrations worldwide and the concentrations of a further six elements (Li, Bo, Tl, La, Er and Co) exceeded the range of soil concentrations previously reported for British soils.

5 Heavy metal and metalloid concentrations in UK herbage

5.1 Introduction

Two sources of heavy metals may be detected when plant tissues are analysed. These are:

- the uptake of metals from soils;
- the deposition of aerosols and particulates from the atmosphere.

It is usually not possible to distinguish the proportion of any metal derived from each source.

The bioavailability of heavy metals (i.e. whether they can be taken up by plants) depends on:

- their chemical form in the soil;
- the influence of soil conditions to transform them;
- the mobility and retention of different chemical forms in soil.

In addition to soil factors, the uptake and accumulation of metals and metalloids by plants is strongly affected by the plant genotype. Species and varieties/strains within a species can vary greatly in their uptake and accumulation. An extreme case is provided by hyperaccumulator species such as *Thlaspi caerulescens*, which can accumulate Cd and Zn.

Plants that grow well in metal-contaminated soil have often developed some form of physiological adaptation (e.g. the retention of metals in below-ground parts of the plant) so that the root forms a barrier to metal transfer to aerial parts of the plant. Since consumption of foliar vegetation and fruit is potentially a major route of entry of metals into terrestrial food chains and the human diet, the retention in plant roots and tubers of certain trace metals has the potential to limit metal transfer and exposure.

Grasses are the principal component of the above-ground herbage samples collected in the UKSHS. These grasses are the main source of food for grazing livestock, the products from which account for a proportion of human exposure to persistent metal compounds.

The discussion of the interpretation of heavy metal uptake and contamination of vegetation in the UKSHS focuses on:

- trace metals analysed that are considered essential for plant and/or animal health – Cr (animals), Cu, Mn, Ni, Zn;
- trace metals analysed that are not essential for plant or animal health – Cd, Cr (not plants), Hg, Pt, Ti, Sn, Pb, As;
- the use of Ti concentrations as an indication of potential contamination of herbage by soil.

V has not yet been conclusively proven to be essential for higher plants, although it is known to be essential for algae.

Even essential elements can be toxic in excessive concentrations.

The full dataset for the concentrations of the 13 heavy metals and metalloids determined in rural herbage collected from sites in England, Northern Ireland, Scotland and Wales (*n* = 366) is presented in Appendix 5 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of herbage.
Histograms with minimum and maximum ranges of concentrations (added as 'bars') are provided for each element for rural herbage (Figure 5.1) and urban herbage (Figure 5.2) for:

- the entire UK dataset;
- England, Northern Ireland, Scotland and Wales individually.

Descriptive statistics for the full dataset and for each of the regions (England, Northern Ireland, Scotland and Wales) are presented in this section of the report in separate tables for each element studied.

A number of sites showed metal herbage concentrations well above the rest of the sampled population. The possibility that this is due to contamination of the herbage sample is discussed in Section 5.5.

Genetic variations in plants (e.g. hyperaccumulators) and variations in soil conditions can affect the relative ease with which plants accumulate elements in individual cases. Kabata-Pendias (2000) gives a general indication of the relative degree of accumulation of elements by plants; the data are based on published papers but provide only a general indication. However, the Kabata-Pendias data provide a useful comparison with the Soil–Plant Concentration Factors given in this UKSHS report. Kabata-Pendias calculated an Index of Bioaccumulation as the ratio of trace elements in plants to their concentration in soils (Table 5.1).

Table 5.1 – Index of Bioaccumulation for green plants (Kabata-Pendias 2000)

Classification	Index of Bioaccumulation	Elements
Elements that 'lack' accumulation	$10^{-3} – 10^{-2}$	Ba Ti, Sc, Zr, Bi, Ga, Fe, Se
Elements with 'slight' accumulation	$10^{-2} – 10^{-1}$	Sb, Be, Cr, I, V, F, Li, Ni, Mn
Elements with 'medium' accumulation	$10^{-1} – 1$	Co, As, Ge, Te, Ag, Sr, Pb, Cu, Hg, Mo, Zn
Elements with 'intensive' accumulation	$1 – 10^{1}$	Rb, Cs, Br, B
Elements with more intensive accumulation	$>10^{1}$	Cd

5.2 Herbage from rural locations

5.2.1 Transition metals in rural herbage

Cadmium (Cd)

Cadmium is not essential for plant growth and is highly toxic to plants and animals. Cd is a relatively mobile trace element in soil and the uptake of Cd by plants growing on contaminated soils and its accumulation in pasture swards or food crops at sub-phytotoxic levels is the main route of exposure for animals and humans.

Relatively large concentrations of Cd can accumulate in edible portions of plants and crops without the plant showing visible symptoms of Cd toxicity. Symptoms of acute Cd toxicity in plants include leaf chlorosis, wilting and stunted growth. Symptoms specific to Cd are rarely seen since phytotoxicity on contaminated land is more commonly due to excesses of other metals present in much higher concentrations (Alloway 1995).

The most common form of Cd in soils (ionic Cd^{2+}) is taken up readily by plants resulting, for example, in plants on metalliferous sites accumulating Cd more readily than plants on soils amended with sewage sludge (Alloway,1995) where Cd is present in organic complexes. Soil pH is generally reported to be the major soil factor controlling the uptake of Cd by plants.

Summary statistics are provided for each of the four countries in Table 5.2 and illustrated in Figure 5.1c.

Table 5.2 – Concentrations of Cd in rural herbage of different countries in the UKSHS (mg/kg)

Cadmium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	0.10–1.43	0.14	0.10	0.12
England	183	0.10–1.43	0.15	0.10	0.15
N. Ireland	30	0.10–0.29	0.13	0.10	0.06
Scotland	120	0.10–0.76	0.13	0.10	0.10
Wales	33	0.10–0.37	0.13	0.10	0.06

Comparative statistics were not performed on these data as a number of the points were at the limit of detection for Cd (0.1 mg/kg).

Mean vegetation Cd concentrations in rural herbage in all four countries were below the range of concentrations quoted in the early data for uncontaminated herbage by Allaway (1968) of 0.2–0.8 mg/kg but well within the range of concentrations quoted for grass herbage by Kabata-Pendias (2000) of 0.03–1.26 mg/kg.

The maximum Cd concentration in rural herbage in England was somewhat higher than these ranges, possibly due to the inclusion of one or two locations close to mining sites. Cd concentrations in all UK rural herbage were much lower than the 3.8–5.0 mg/kg range reported for grass herbage in a metal-contaminated woodland (Martin and Coughtrey 1987) or the 4.9–9.5 mg/kg range reported for sewage-sludge amended soils by Alloway (1995).

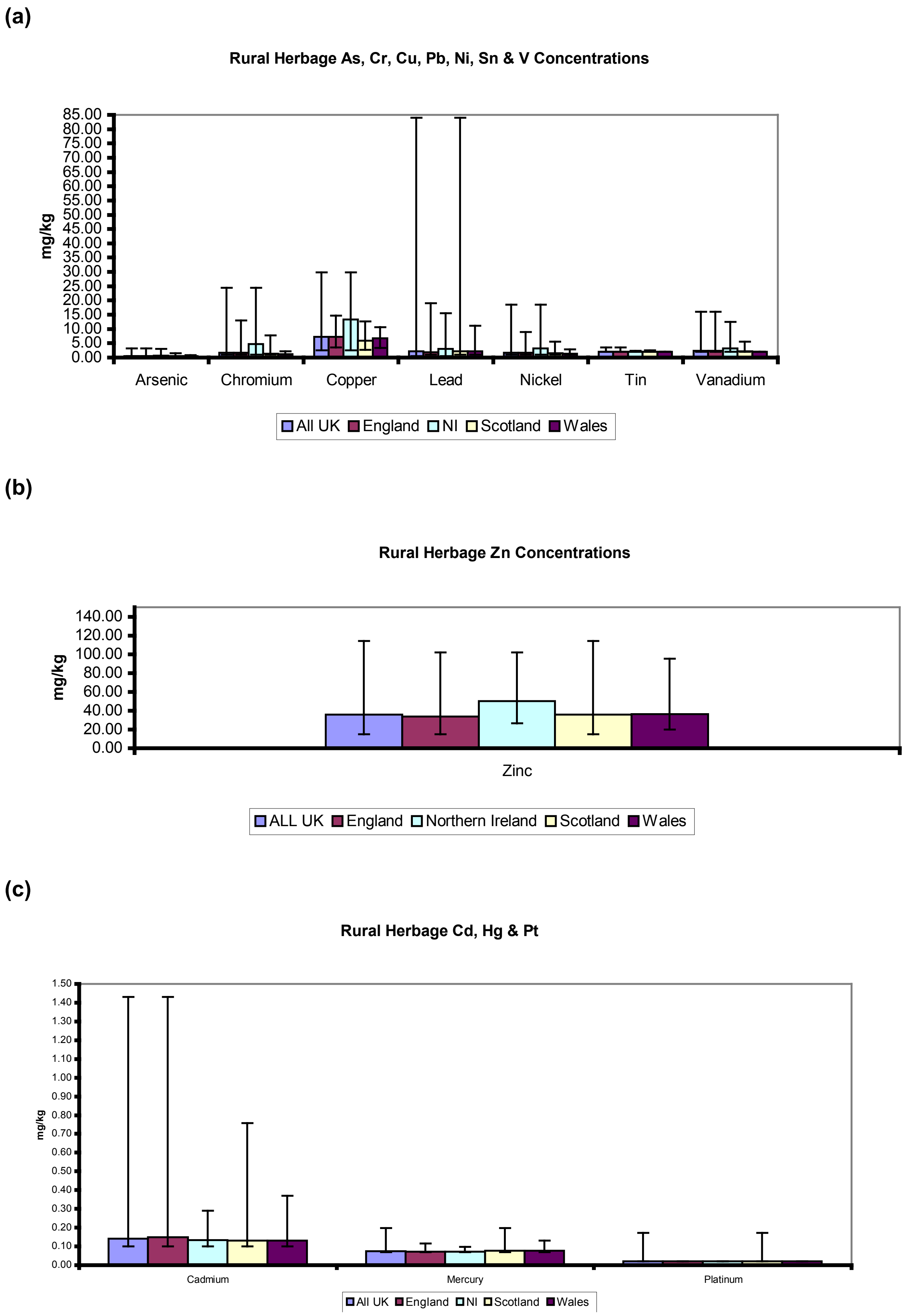


Figure 5.1 – Means and ranges of metal/metalloid concentrations in rural herbage

Chromium (Cr)

Chromium is not essential for plant growth but is an essential element for human health. Since the bulk of Cr in soils is insoluble and not bioavailable, plants generally take up very low quantities of Cr, resulting in low concentrations in plant tissues. Most of the Cr taken up by plants remains in root tissue, so that there is rarely any relationship between the Cr concentration of foliage and total Cr concentrations in soil.

Summary statistics are provided for each of the four countries in Table 5.3 and illustrated in Figure 5.1a.

Table 5.3 – Concentrations of Cr in rural herbage of different countries in the UKSHS (mg/kg)

Chromium	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	1.0–24.5	1.76	1.00	2.14
England	183	1.0–13.0	1.62	1.00	1.58
N. Ireland	30	1.0–24.5	4.70	2.49	5.21
Scotland	120	1.0–7.71	1.40	1.00	1.07
Wales	33	1.0–2.24	1.18	1.00	0.34

Comparative statistics were not performed on these data as a number of the points are at the limit of detection for Cr (1 mg/kg).

The range of Cr concentrations in rural vegetation in England, Scotland and Wales was within the range quoted in the early data for generally uncontaminated sites (Allaway 1968) of 0.03–15 mg/kg and can be compared with the range quoted for forage plants (Kabata-Pendias 2000) of 0.11–3.4 mg/kg. Maximum Cr concentrations that exceeded these ranges were found only in Northern Ireland. While all rural herbage samples analysed exceeded the Cr concentrations reported for plants grown in ‘clean’ soils (e.g. Cary *et al.* 1977, Larsen *et al.* 1992) of 0.005–0.33 and 0.01–0.3 mg/kg respectively, the majority of Cr rural herbage concentrations throughout the UK were much lower than the range of 10–190 mg/kg quoted by Breeze (1973) for plants growing on Cr-contaminated soils (chromium mine wastes). The upper concentrations in the ranges may be due to soil/atmospheric contamination.

The highest Cr concentration found in UK rural herbage came from just one sample in Northern Ireland. The Northern Ireland herbage Cr concentrations showed the widest distribution of values of all UK data. This pattern mimics the wide distribution of Cr concentrations found in rural soil in Northern Ireland. The high Cr concentration in Northern Ireland is probably linked to the geology (higher Cr in mafic rocks).

Copper (Cu)

Copper is an important essential element for both plant and animal growth. In general, the concentration of Cu in plant tissues seems to be a function of its level in the nutrient solution or in soils (Kabata-Pendias 2000). The uptake of Cu by plants increases at low pH since acidic conditions increase soluble and bioavailable forms of Cu. Cu uptake by plants varies widely between species and between cultivars within species. Vesicular-arbuscular (VA) mycorrhizae enhance the uptake of Cu by plant roots.

Summary statistics are provided for each of the four countries in Table 5.4 and illustrated in Figure 5.1a.

Table 5.4 – Concentrations of Cu in rural herbage of different countries in the UKSHS (mg/kg)#

Copper	*n*	Range	Mean	Median	SD
UK	366	2.49–29.9	7.26	6.54	3.46
England	183	3.56–14.6	7.22^{b}	7.03	2.28
N. Ireland	30	2.49–29.9	13.3^{a}	11.8	7.00
Scotland	120	2.68–12.7	5.96^{c}	5.28	2.22
Wales	33	3.45–10.6	6.71^{b}	6.63	1.97

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Table 5.5 – Range of Cu concentrations reported in herbage worldwide (mg/kg)

Reference	Range for various countries	Mean for various countries
Kabata-Pendias (2000)	1.1–33.1	1.8–10.5

Mean Cu concentrations found in UK rural herbage lay within the range of Cu concentrations in the early data quoted for generally uncontaminated vegetation (Allaway 1968) of 4–15 mg/kg and were close to the range of Cu concentrations quoted for forage plants growing on uncontaminated soils (Kabata-Pendias 2000) of 3.9–11.5 mg/kg. They were also close to the range of mean concentrations for herbage worldwide reported by Kabata-Pendias (2000) (Table 5.5). Only in Northern Ireland did maximum Cu concentrations in rural herbage exceed these ranges. Maximum Cu concentrations in rural vegetation in England, Scotland and Wales lie within ranges found for grass herbage in both uncontaminated (Kubota 1983) and contaminated (Martin and Coughtrey 1981) conditions of 10–20 mg/kg and 16.6–20 mg/kg respectively.

The widest range of Cu concentrations in rural herbage was found in Northern Ireland. This pattern reflects a higher mean Cu concentration and a relatively wide spread of Cu concentrations in Northern Ireland rural soils compared with the rest of the UK. The mean Cu concentration in rural herbage in Northern Ireland was significantly higher than in the other three countries.

The upper concentrations of Cu seem relatively high as grasses rarely accumulate more than 20 mg/kg in their leaves. The generally accepted concentration of Cu in herbage at which the risk of Cu toxicity occurs in susceptible animal species (e.g. sheep) is 10 mg/kg (dry matter). These high concentrations may be due to soil contamination or atmospheric deposition. Cu and other trace metal concentrations in herbage vary throughout the year, with autumn/winter usually the period of highest concentrations.

Manganese (Mn)

Manganese is an essential element for both plant and animal growth. There is evidence to show that manganese oxides are solubilised (Bromfield 1958a, Bromfield 1958b) and that there are higher concentrations of extractable Mn (Godo and Reisenauer 1980) in the rhizosphere of plants than in the bulk soil. These characteristics have been attributed to the presence of root exudates, acting as complexing agents increasing Mn availability, and to the higher pH in the rhizosphere. Despite these effects, Mn is the trace element most commonly deficient in cereal crops in the UK.

Summary statistics are provided for each of the four countries in Table 5.6.

Table 5.6 – Concentrations of Mn in rural herbage of different countries in the UKSHS (mg/kg)#

Manganese	*n*	Range	Mean	Median	SD
UK	366	18.9–1,300	244	182	206
England	183	18.9–621	178^{b}	120	150
N. Ireland	30	72–627	238^{a}	214	129
Scotland	120	26.7–1,300	334^{a}	244	264
Wales	33	46.8–748	282^{a}	267	161

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Mean Mn concentrations in UK rural herbage lie well within the ranges in the early data reported for vegetation from generally uncontaminated sites (Allaway 1968) of 15–1,000 mg/kg. As with Cu and Cr, the Mn concentrations seem very high, possibly due to soil contamination. The mean concentration in England was significantly lower than in the other three countries. Kabata-Pendias (2000) reported a worldwide range of 17–334 mg/kg (dry matter) in grass and stated that toxicity tends to occur in plants with Mn concentrations of over 500 mg/kg.

On the basis of this threshold of toxicity, herbage from all four countries had maximum Mn concentrations that exceeded this value. Berrow and Burridge (1979) reported the ranges of Mn concentration of grasses and clovers in UK herbage as 79–160 mg/kg and 31–65 mg/kg respectively.

While the maximum values in all four regions of the UK exceeded the range reported by Berrow and Burridge (1979), only in Scotland were maximum Mn concentrations in rural herbage higher than the general Mn range in herbage from uncontaminated soils reported by Allaway (1968). However, the maximum values in all four regions exceeded the more recent general worldwide Mn range in herbage reported by Kabata-Pendias (2000).

The spread of Mn concentrations was wide and the mean Mn concentration in Scottish rural herbage was higher than in all other regions of the UK. Since Mn concentrations from only one rural site in Scotland were significantly higher than in the rest of the UK, this is a surprising result. The possibility that this higher result was due to contamination of the herbage by soil is discussed in Section 5.5.

Mercury (Hg)

Mercury is not essential for plant growth. Availability of soil Hg to plants is low, with a general tendency for plants to accumulate Hg in roots, so that the root acts as a barrier to Hg transfer into foliage. Lindberg *et al*. (1979) found that the fraction of Hg retained in the roots of plants growing near a mercury mine was around 20 times higher than concentrations of Hg in foliage.

Summary statistics are provided for each of the four countries in Table 5.7 and illustrated in Figure 5.1c.

Table 5.7 – Concentrations of Hg in rural herbage of different countries in the UKSHS (mg/kg)

Mercury	*n*	Range	Mean	Median	SD
UK	366	0.07–0.20	0.07	0.07	0.01
England	183	0.07–0.12	0.07	0.07	0.01
N. Ireland	30	0.07–0.10	0.07	0.07	0.01
Scotland	120	0.07–0.20	0.08	0.07	0.02
Wales	33	0.07–0.13	0.08	0.07	0.02

No comparative statistics were performed on these data as the results were dominated by values at the limit of detection (0.07 mg/kg). All Hg concentrations in rural herbage throughout the UK lay well within the 0.005–0.5 mg/kg early range of values quoted as being typical of vegetation growing on generally uncontaminated sites (Allaway 1968) and can be compared with the range of 0.003–0.086 mg/kg reported by Kabata-Pendias (2000) for a range of food plants.

The median Hg concentration for the UKSHS herbage samples in all four countries was below the level of 0.1 mg/kg (100 ppb) which Kabata-Pendias (2000) observed was not exceeded in grass and feed legumes in the dry matter. All UK rural herbage results lay within the range of 0.004–0.4 mg/kg reported by MacLean (1974) for plants growing on ‘clean’ soil for use as a control in crop experiments. Hg concentrations in all UK rural herbage were considered to be low.

Nickel (Ni)

Nickel has only relatively recently (1970s–1980s) been shown to be an essential element for plant growth. However, Ni deficiencies are unlikely since the small concentrations required are likely to be readily available in soil and Ni is rapidly taken up from soils by plants. Ni is also an essential element for animals and humans.

The concentration of Ni in plants generally reflects that of the soil, particularly the soluble Ni fraction in soil. This fraction in turn is influenced by soil pH. Plants growing in serpentine soils have developed tolerance to high Ni concentrations and some are even classified as hyperaccumulators since their uptake of Ni is so high, i.e. concentrations >1,000 mg/kg (Brooks 1987).

Summary statistics provided for each of the four countries in Table 5.8 and illustrated in Figure 5.1a.

Table 5.8 – Concentrations of Ni in rural herbage of different countries in the UKSHS (mg/kg)#

Nickel	*n*	Range	Mean	Median	SD
UK	366	1.00–18.60	1.76	1.10	1.47
England	183	1.00–8.97	1.72^{b}	1.19	1.12
N. Ireland	30	1.00–18.60	3.23^{a}	2.29	3.61
Scotland	120	1.00–5.57	1.55^{b}	1.00	0.92
Wales	33	1.00–2.80	1.38^{b}	1.00	0.56

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

Mean Ni concentrations in all four countries lay within the 0.02–5 mg/kg range reported for vegetation growing in generally uncontaminated sites (Allaway 1968) and the range of 0.1–5 mg/kg reported for plants growing in non-serpentine soils (Freedman and Hutchinson 1981).

Rural herbage in Northern Ireland had a significantly higher concentration than the other three countries. This reflects the trend for rural soils. Maximum values of Ni in rural herbage from England, Northern Ireland and Scotland exceeded these ranges but can be compared with the ranges of 12–23 mg/kg (Slingsby and Brown 1977) and 20–100 mg/kg (Farago and Cole 1988) found for plants growing in serpentine soils.

All rural herbage Ni concentrations lay well below the Ni concentrations of up to 1,000 mg/kg found in hyperaccumulator plants growing in serpentine soils (Brookes 1987). Kabata-Pendias (2000) reported mean values of 0.1–1.7 mg/kg in grasses and 1.2–2.7 mg/kg in clovers, and gave ranges of <0.07–4.7 mg/kg for grasses and <0.5–8.2 mg/kg for clover.

Platinum (Pt)

Platinum is not essential for plant growth. Very little is known about the uptake and distribution of Pt in plants and crops. In vegetation, Pt accumulation appears to occur in the order roots > leaves > shoots. The few studies that have been made of Pt uptake by plants showed that only 1–3 per cent of soil Pt is taken up by plants (e.g. Lustig *et al.* 1997, Verstraete *et al.* 1998).

Herbage samples are likely to have some atmospherically deposited Pt on them from catalytic converters in cars. This is most likely to occur in more highly populated areas with a higher density of roads, etc. – even though the sample sites are not close to roads.

Summary statistics are provided for each of the four countries in Table 5.9 and illustrated in Figure 5.1c.

Table 5.9 – Concentrations of Pt in rural herbage of different countries in the UKSHS (mg/kg)

Platinum	*n*	Range	Mean	Median	SD
UK	366	0.02–0.02	0.02	0.02	0.01
England	183	0.02–0.02	0.02	0.02	0.00
N. Ireland	30	0.02–0.02	0.02	0.02	0.00
Scotland	120	0.02–0.02	0.02	0.02	0.01
Wales	33	0.02–0.02	0.02	0.02	0.00

No comparative statistical analyses were performed on these data as they reflected the limit of detection for Pt (0.02 mg/kg). Pt concentrations in rural herbage have been reported to be <0.001 mg/kg for un-mineralised soils and 0–0.275 mg/kg at 'mineralised' sites of (Rencz and Hall 1992).

Pt concentrations in all UK rural herbage appeared to be well below the range of concentrations (0.1–0.83 mg/kg) found in herbaceous plants growing on ultrabasic soils (Valente *et al.* 1982). Very low Pt concentrations in rural herbage were reported in two studies from the USA. Helmers *et al*. (1998) reported a range of 0.0034–0.0077 mg/kg in grass adjacent to a highway and Ely *et al*. (2001) reported a range of 0.0012–0.0017 in washed and unwashed grass samples from the verges of a heavily used (24,350 vehicles per day) toll road in Indiana.

Titanium (Ti)

Titanium is not essential for plant growth and it is not readily taken up by plants as it is generally present in insoluble compounds in soil that are not bioavailable. Since Ti concentrations in soil are high (1,000-3,000 mg/kg) and concentrations in plants are low (<1 mg/kg), Ti has been used experimentally to detect soil contamination of vegetation. This approach was also used in the UKSHS.

Kabata-Pendias (2000) stated that there is some evidence that Ti may have a beneficial impact on carbohydrate metabolism in plants, but it has not yet proved to be an essential trace element. This implies that some Ti is normally taken up by plants and should be borne in mind when considering the use of Ti as an indicator of soil contamination.

Summary statistics are provided for each of the four countries in Table 5.10.

Table 5.10 – Concentrations of Ti in rural herbage of different countries in the UKSHS (mg/kg)

Titanium	*n*	Range	Mean	Median	SD
UK	366	1.84–149	11.4	5.00	19.2
England	183	1.84–96.3	8.02	5.00	10.8
N. Ireland	30	5–149	33.9	8.79	43.0
Scotland	120	5–111	12.5	8.79	43.0
Wales	33	5–11.1	5.53	5.00	1.28

No comparative statistics were performed on these data as many were at the limit of detection for Ti (5 mg/kg). There are few studies of Ti concentrations in herbage. However, the ranges of UK rural herbage Ti concentrations in England, Northern Ireland and Scotland went higher than the range of Ti concentrations reported in various food plants by Kabata-Pendias (2000) of 0.2–80 mg/kg but lower than Ti concentrations reported for grass pasture in Oregon, USA, (218 mg/kg) by Mayland and Sneva (1983). The herbage in Oregon was growing on soil that was relatively high in Ti (4,785 mg/kg) compared with Ti concentrations in UK rural soils (13–3,000 mg/kg). Ti concentrations in Northern Ireland showed the widest spread of results.

Vanadium (V)

Vanadium has not yet been conclusively proven to be essential for higher plants, although it is known to be essential for algae. Few studies have examined V concentrations in plants. There is evidence to suggest that V is a specific catalyst of nitrogen fixation and may partially substitute for Mo in this function, which is carried out particularly by *Rhizobium* bacteria. High accumulation of V has been observed in the nodules of several legume plants.

Mobile forms of V appear to be easily taken up by roots and some plants appear to be able to accumulate the metal in their tissues. Shacklette *et al*. (1978) reported the mean concentration of V in vegetables to be <5 to 50 mg/kg. Bryophytes are particularly sensitive to aerial sources of V, with the mean concentration of V in bryophytes reported to be 11 mg/kg (Bowen 1979).

Summary statistics are provided for each of the four countries in Table 5.11 and illustrated in Figure 5.1a.

Table 5.11 – Concentrations of V in rural herbage of different countries in the UKSHS (mg/kg)

Vanadium	*n*	Range	Mean	Median	SD
UK	366	2.0–16.1	2.30	2.00	1.34
England	183	2.0–16.1	2.29	2.00	1.46
N. Ireland	30	2.0–12.5	3.24	2.00	2.51
Scotland	120	2.0–5.58	2.17	2.00	0.65
Wales	33	2.0–2.0	2.00	2.00	0.00

No comparative statistics were performed on these data as many were at the limit of detection for vanadium (2 mg/kg). V concentrations in rural herbage in the UKSHS lay well within the range reported by Shacklette *et al*. (1978). However, the UKSHS rural herbage V concentrations were higher than the range of 0.18–0.42 mg/kg (dry weight basis) reported for grass shoots by Kabata-Pendias (2000). V concentrations from just three sites (two in England and one in Northern Ireland) skewed the overall dataset, giving a higher mean and variance – particularly in the Northern Ireland data. The possibility that these few higher results were due to contamination of the herbage by soil is discussed in Section 5.5.

Zinc (Zn)

Zn is an essential element for plant and animal growth. In soil, Zn is a relatively mobile trace element, with both inorganic Zn^{2+} and Zn organic chelates being taken up by plants (e.g. Loneragan 1975). Marschner (1993) offers a more recent and comprehensive reference on zinc.

Factors influencing the solubility of Zn in soils (pH, cation exchange capacity (CEC), moisture content) influence the availability of Zn for uptake by plants. Although the concentration of Zn in plants tends to reflect the concentration of Zn in soils, Zn uptake amounts vary widely between plant species and cultivars.

Summary statistics are provided for each of the four countries in Table 5.12 and Illustrated in Figure 5.1b.

Table 5.12 – Concentrations of Zn in rural herbage of different countries in the UKSHS (mg/kg)#

Zinc	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	14.7–114	35.9	32.6	14.6
England	183	14.7–102	33.6^{a}	32.0	11.8
N. Ireland	30	26.6–102	49.9^{b}	41.9	18.2
Scotland	120	15.1–114	35.6^{a}	31.3	15.3
Wales	33	19.9–95.4	36.4^{a}	33.6	15.9

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The mean concentration of Zn in Northern Ireland rural herbage was significantly above that in England, Wales and Scotland despite the rural soil concentration being somewhat lower than in England. All Zn concentrations in UK rural herbage lie well within the early range of values (8–400 mg/kg) found in plants growing in uncontaminated soils (Allaway 1968). All rural herbage Zn concentrations were also much lower than the 323 mg/kg reported by Martin and Coughtrey (1987) for grasses in a metal-contaminated woodland near Bristol. Kabata-Pendias (2000) gave a background range of Zn in grass as 12–47 mg Zn kg^{-1} and quoted values of 65–350 mg/kg for grass grown on contaminated soils. The maximum Zn concentrations in the UKSHS herbage samples are relatively high but the means and medians fall within the background range quoted by Kabata-Pendias (2000).

5.2.2 Other metals in rural herbage

Tin (Sn)

Tin is not essential for plant growth. Few data exist on Sn concentrations in herbage.

Summary statistics are provided for each of the four countries in Table 5.13 and illustrated in Figure 5.1a.

Table 5.13 – Concentrations of Sn in rural herbage of different countries in the UKSHS (mg/kg)

Tin	*n*	Range	Mean	Median	SD
UK	366	2.00–3.47	2.01	2.00	0.09
England	183	2.00–3.47	2.01	2.00	0.11
N. Ireland	30	2.00–2.43	2.01	2.00	0.08
Scotland	120	2.00–2.55	2.00	2.00	0.05
Wales	33	2.00–2.00	2.00	2.00	0.00

All Sn concentrations in rural herbage lie within the early range of Sn values (0.2–6.8 mg/kg) reported for vegetation growing on generally uncontaminated soils (Allaway 1968). They were just higher than the range of values (0.2–1.9 mg/kg) reported by Chapman (1972) for grasses. As for Sn concentrations in rural soils, the range of Sn concentrations in rural herbage was highest in England, probably reflecting higher values from rural locations closest to mining sites in Devon and Cornwall.

Lead (Pb)

Lead is not essential for plant growth. Although there is generally a positive relationship between the concentration of lead in soil and that in plants (e.g. Korcak and Fanning 1985), it is relatively insoluble and immobile, so that only a small proportion of the Pb in soil is available for uptake by plants. In addition, several authors (e.g. Tjell *et al.* 1979) have shown that >90 per cent of the Pb in plants comes from foliar uptake of aerially-deposited Pb. To compound these findings, Mitchell and Reith (1966) showed an order of magnitude difference in Pb concentrations of grass harvested in summer compared to winter (though this assessment was based on conditions that prevailed 40 years ago). Adriano (2001) discusses atmospheric deposition of Pb onto vegetation in detail, especially the effect of leaf surface.

Lead in soil and dust are considered to be the main sources of Pb intake by humans. These are particularly important sources of exposure for young children.

Summary statistics are provided for each of the four countries in Table 5.14 and illustrated in Figure 5.1a.

Table 5.14 – Concentrations of Pb in rural herbage of different countries in the UKSHS (mg/kg)#

Lead	n	Range	Mean	Median	SD
UK	366	0.47–84	2.12	1.00	4.77
England	183	1.0–19.1	1.87^{b}	1.00	2.11
N. Ireland	30	0.47–15.5	3.07^{a}	1.61	3.69
Scotland	120	1.0–84	2.23^{b}	1.00	7.61
Wales	33	1.0–11.1	2.22^{ab}	1.33	2.28

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Mean Pb concentrations in rural herbage lay well within the early range of concentrations (0.1–10 mg/kg) found in plants from generally uncontaminated sites (Allaway 1968). Early data from Mitchell and Reith (1966) compared Pb concentrations for grass harvested in summer (0.3–1.5 mg/kg) and in autumn (10 mg/kg). By winter, the Pb concentration had risen to 30–40 mg/kg. There has been some uncertainty about whether the apparent increase in Pb during winter was due to higher deposition from the atmosphere or increased translocation from the roots. However, these differences in Pb concentration between the growing season and winter are not relevant for UKSHS samples, the vast majority of which were sampled during the growing season (between April and October). Mean Pb concentrations in rural herbage from all four countries were low compared with some of the herbage analysed in these previous studies.

Kabata-Pendias (2000) quotes an average ‘background’ Pb concentration of 2.1 mg/kg for grasses and 2.5 mg/kg for legumes. The mean values for the UKSHS samples were close to these values, but the maximum concentrations were relatively high and indicative of atmospheric pollution and/or significantly contaminated soils. The highest maximum Pb concentrations in the UKSHS, found in Scottish rural herbage, were greater than the 54–63 mg/kg range of concentrations found in grasses from a metal-contaminated woodland (Martin and Coughtrey 1987).

Wherever grasses with hairy leaves (e.g. *Holcus lanatus*) were sampled in the UKSHS, it would be expected that Pb would be retained more tenaciously but, with the ban on lead in petrol, this is not likely to have been as important as it would have been previously. Kabata-Pendias (2000) quoted Dalenberg and van Driel (1990), who stated that <95 per cent of Pb in plants may result from aerial deposition on leaves.

5.2.3 Metalloids in rural herbage

Arsenic (As)

Arsenic is not essential for plant growth. All As compounds are toxic though the toxicity varies. For example, inorganic arsenic such as As combined with oxygen or sulphur is thought to be the most toxic, while most organic compounds containing As are thought to be less toxic.

In the Index of Bioaccumulation given by Kabata-Pendias (2000) (Table 5.1), As is shown in the ‘medium’ accumulation group (with Cu, Pb and Zn) and having an Index of 10^{-1} to 1. O’Neil (1995) reported that, even on soils with relatively high As concentrations, plants do not usually contain dangerous levels of As. While grasses growing on contaminated sites can show very high As concentrations (>3,000 mg/kg), Porter and Peterson (1977) reported it was rare to see elevated (>1 mg/kg) As concentrations in crops. MAFF (1982) reported that the level of As in edible plants was generally very low even when crops are grown in contaminated soils. However, Kabata-Pendias (2000) gave a range of 0.009–1.5 mg/kg in plants grown on uncontaminated soils and also reported concentrations of 1.1–5.4 mg/kg with grasses from a semi-arid climatic zone; grass from contaminated mining sites in the UK was quoted as containing 460–6,640 mg/kg. Some leafy vegetable food crops can accumulate considerable concentrations of As (Alloway B J, personal communication).

Summary statistics are provided for each of the four countries in Table 5.15 and illustrated in Figure 5.1a.

Table 5.15 – Concentrations of As in rural herbage of different countries in the UKSHS (mg/kg)

Arsenic	***n***	**Range**	**Mean**	**Median**	**SD**
UK	366	0.50–3.21	0.56	0.50	0.28
England	183	0.50–3.21	0.57	0.50	0.31
N. Ireland	30	0.50–3.04	0.74	0.50	0.54
Scotland	120	0.50–1.45	0.53	0.50	0.12
Wales	33	0.50–0.78	0.51	0.50	0.05

Table 5.16 – Concentrations of As in vegetation in different countries (mg/kg)

Study	Range	Mean	Median
UKSHS	0.50–3.21	0.56	0.50
Kabata-Pendias (2000)[1]	0.009–1.5	–	–
Kabata-Pendias (2000)[2]	1.1–5.4	–	–
Kabata-Pendias (2000)[3]	20–330	–	–
Kabata-Pendias (2001)[4]	460–6640	–	–
Larsen *et al*. (1992)[5]	<0.01–0.48	–	–
Porter and Peterson (1977)[6]	–	3	–
Porter and Peterson (1977)[7]	–	3460	–

[1] As in plants
[2] As in grasses from a semi-arid climatic zone
[3] As in forage grass and clover
[4] grasses from mining contaminated sites in the UK
[5] crops on soils around a wood preservation factory
[6] grasses growing on uncontaminated soils
[7] grasses growing on old spoil tips from As mine spoil

The majority of As concentrations in the UKSHS rural herbage were lower than the 3 mg/kg reported by Porter and Peterson (1977) for plants growing in uncontaminated soils (Table 5.16) and well below the range of 20–330 mg/kg found in forage grass and clover (Kabata-Pendias 2000). The maximum As concentrations in both England and Northern Ireland were similar to the concentration reported by Porter and Peterson (1977) for plants growing in uncontaminated soils.

5.2.4 Conclusions on heavy metals and metalloids in rural herbage

Ranges of Cd, Hg, Zn and Sn concentrations in rural herbage are well within ranges of concentrations found in other studies of trace metals in vegetation. For the majority of other metals studied (Cr, Cu, Mn, Ni, Pb, As), the mean concentration in rural soils is well within the range of concentrations found in other studies of trace metals in vegetation.

Statistical analyses of the differences between the four countries were performed for only four determinands (Cu, Ni, Mn and Zn) as many results for the other elements were at their limit of detection.

Cu and Ni concentrations in rural herbage were significantly higher in Northern Ireland, mirroring the results for rural soil. For Mn and Zn, no clear patterns were observed.

The relatively high maximum Cr, Cu and Mn concentrations found in some herbage samples from England and Scotland might warrant further investigation to determine whether these are due to soil–plant accumulation facilitated by low pH, etc. or from contamination by soil or atmospheric deposits.

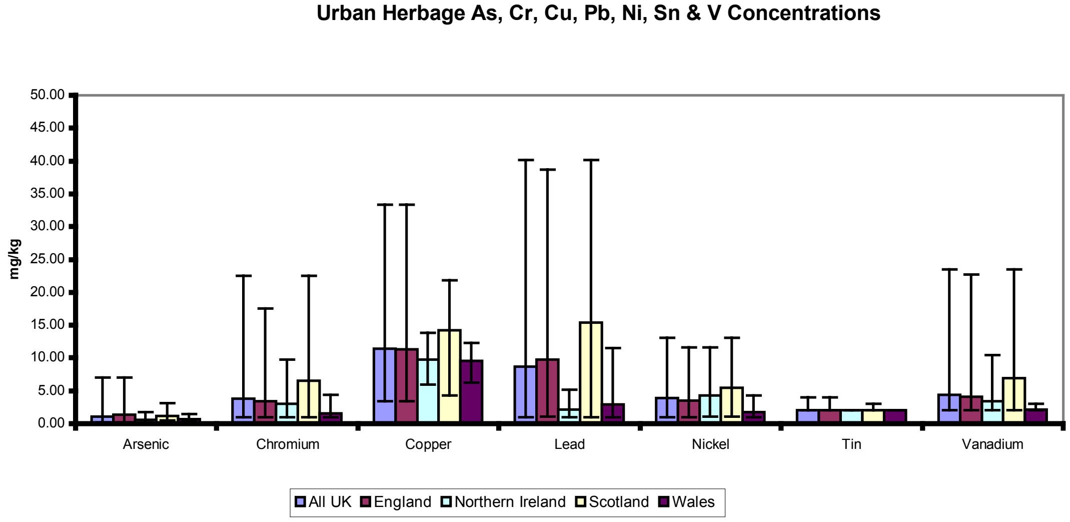
5.3 Herbage from urban locations

The full dataset for the concentrations of the 13 heavy metals and metalloids determined in herbage collected from sites in 29 towns and cities in England, Northern Ireland, Scotland and Wales (*n* = 87) is presented in Appendix 6 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of herbage.

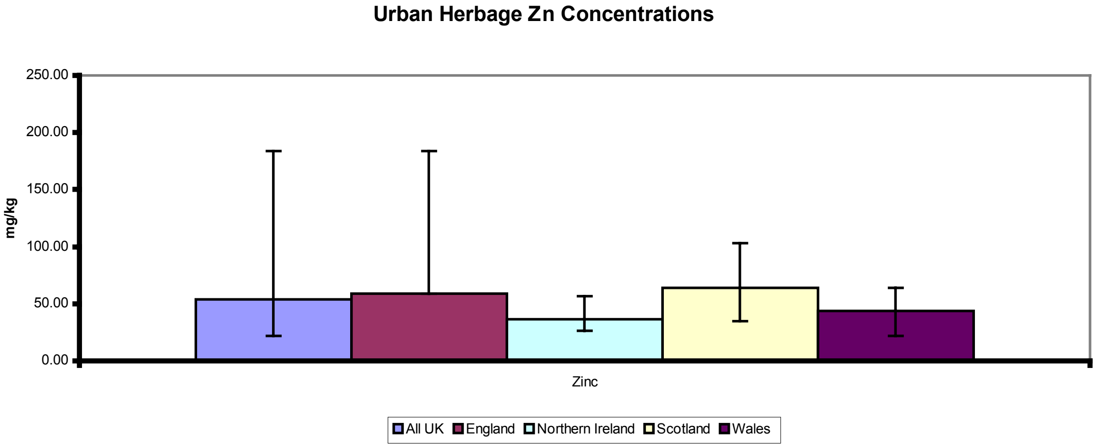
Descriptive statistics for the full dataset and for each of the regions (England, Northern Ireland, Scotland and Wales) are presented in this section of the report in separate tables for each element studied.

This section of the report discusses general levels and patterns of trace metals in urban herbage. Results are compared with rural soil concentrations and other, previous studies of trace metals in urban herbage where such data are available.

(a)



(b)



(c)

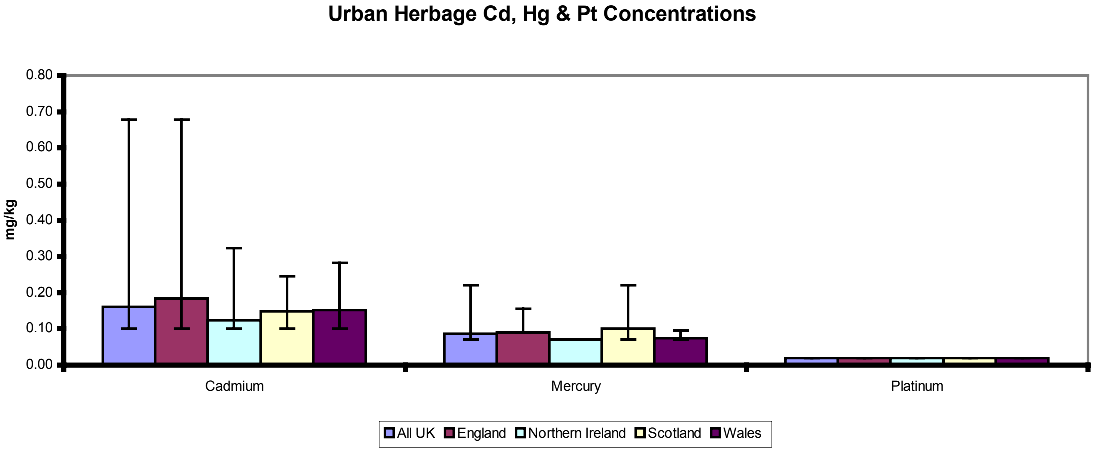


Figure 5.2 – Means and ranges of metal/metalloid concentrations in urban herbage

5.3.1 Transition metals in urban herbage

Cadmium (Cd)

Summary statistics are provided for each of the four countries in Table 5.17 and illustrated in Figure 5.2c.

Table 5.17 – Concentrations of Cd in urban herbage of different countries in the UKSHS (mg/kg)

Cadmium	*n*	Range	Mean	Median	SD
UK	87	0.1–0.68	0.16	0.11	0.10
England	42	0.1–0.68	0.18	0.13	0.13
N. Ireland	18	0.1–0.32	0.12	0.10	0.06
Scotland	18	0.1–0.25	0.15	0.15	0.05
Wales	9	0.1–0.28	0.15	0.11	0.07

The range of Cd concentrations in urban herbage in all four countries was slightly lower than that in rural herbage (0.1–1.43 mg/kg) (Table 5.2) and not too different to the early range quoted generally for uncontaminated herbage by Allaway (1968) of 0.2–0.8 mg/kg. However, many results were at the limit of detection for Cd (0.1 mg/kg).

The finding that Cd concentrations are lower in urban herbage than rural samples is very interesting. Possible reasons include:

- the sources of Cd in soils – perhaps from phosphate fertilisers, sewage sludges
- deposition in rural areas – possibly from distant industrial sources.

Chromium (Cr)

Summary statistics are provided for each of the four countries in Table 5.18 and illustrated in Figure 5.2a.

Table 5.18 – Concentrations of Cr in urban herbage of different countries in the UKSHS (mg/kg)

Chromium	*n*	Range	Mean	Median	SD
UK	87	1.0–22.5	3.78	1.88	4.10
England	42	1.0–17.5	3.43	1.16	3.89
N. Ireland	18	1.0–9.76	2.99	1.09	3.02
Scotland	18	1.0–22.5	6.53	5.82	5.23
Wales	9	1.0–4.38	1.55	1.00	1.11

The range of Cr concentrations in urban vegetation in the UK was similar to that for rural vegetation (1–24.5 mg/kg) (Table 5.3) and only a little higher than the early range quoted for generally uncontaminated sites (Allaway 1968) of 0.03–15 mg/kg. While the maximum Cr concentrations in rural herbage were highest in Northern Ireland, the maximum Cr concentrations in urban herbage were in Scotland.

Copper (Cu)

Summary statistics are provided for each of the four countries in Table 5.19 and illustrated in Figure 5.2a.

Table 5.19 – Concentrations of Cu in urban herbage of different countries in the UKSHS (mg/kg)#

Copper	*n*	Range	Mean	Median	SD
UK	87	3.42–33.3	11.4	10.3	5.23
England	42	3.42–33.3	11.3[b]	9.80	6.19
N. Ireland	18	5.96–13.8	9.7[b]	9.20	2.25
Scotland	18	4.27–21.8	14.2[a]	15.2	5.06
Wales	9	6.27–12.3	9.52[b]	10.0	1.80

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The overall range of Cu concentrations found in UK urban herbage was similar to the overall range found in UK rural herbage (2.49–29.9 mg/kg) (Table 5.4). The mean Cu concentration in Scottish urban herbage was significantly higher that that in Wales and Northern Ireland. However, the highest mean Cu concentration in rural vegetation was in Northern Ireland. The majority of concentrations in urban vegetation lay within the early range of Cu concentrations quoted for generally uncontaminated vegetation (Allaway 1968) of 4–15 mg/kg. Maximum Cu concentrations in urban herbage in both England and Scotland exceeded this range.

Manganese (Mn)

Summary statistics are provided for each of the four countries in Table 5.20.

Table 5.20 – Concentrations of Mn in urban herbage of different countries in the UKSHS (mg/kg)#

Manganese	*n*	Range	Mean	Median	SD
UK	87	15.1–683	207	161	154
England	42	15.1–683	221[abc]	180	184
N. Ireland	18	82.8–498	179[b]	129	107
Scotland	18	89.6–537	256[a]	245	125
Wales	9	29.2–206	98.2[c]	108	60.4

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of Mn concentrations in UK urban herbage was lower than in rural vegetation (18.9–1,300 mg/kg) (Table 5.6) and well within the ranges found in the early data for vegetation from generally uncontaminated sites (Allaway 1968) of 15–1,000 mg/kg. The mean concentration in Wales was lower than in England, Northern Ireland and Scotland.

If results from the highest site are excluded, the range of values in English cities and towns would be 15–530 mg/kg. The possibility that the higher results were due to contamination of the herbage by soil is discussed in Section 5.5.

Kabata-Pendias (2000) stated that most plants show a toxic response to Mn concentrations of around 500 mg/kg (dry matter). This is likely to be Mn within the plant and not surface contamination. Kabata-Pendias (2000) also stated that Mn was not considered a polluting metal in soils (though Mn contents in soils are known to increase with sewage sludge applications, etc.).

Mercury (Hg)

Summary statistics are provided for each of the four countries in Table 5.21 and illustrated in Figure 5.2c.

Table 5.21 – Concentrations of Hg in urban herbage of different countries in the UKSHS (mg/kg)

Mercury	*n*	Range	Mean	Median	SD
UK	87	0.07–0.22	0.09	0.07	0.03
England	42	0.07–0.16	0.09	0.07	0.03
N. Ireland	18	0.07–0.07	0.07	0.07	0.00
Scotland	18	0.07–0.22	0.10	0.10	0.04
Wales	9	0.07–0.10	0.07	0.07	0.01

The range of Hg concentrations in urban herbage throughout the UK was very similar to that found in rural herbage (0.07–0.2 mg/kg) (Table 5.7) and well within the 0.005–0.5 mg/kg early range of values quoted as being typical of vegetation growing on generally uncontaminated sites (Allaway 1968).

Nickel (Ni)

Summary statistics are provided for each of the four countries in Table 5.22 and illustrated in Figure 5.2a.

Table 5.22 – Concentrations of Ni in urban herbage of different countries in the UKSHS (mg/kg)#

Nickel	*n*	Range	Mean	Median	SD
UK	87	1.0–13.1	3.88	3.09	2.88
England	42	1.0–11.6	3.48^{a}	2.84	2.54
N. Ireland	18	1.04–11.6	4.27^{a}	3.82	2.63
Scotland	18	1.03–13.1	5.50^{a}	5.52	3.62
Wales	9	1.00–4.31	1.77^{b}	1.00	1.24

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The overall range of Ni concentrations in urban herbage in the UK was a little lower than in rural herbage (1.0–18.6 mg kg^{-1}) (Table 5.8) and, as with rural vegetation, it was higher than the early range of Ni concentrations reported for vegetation growing in generally uncontaminated sites (Allaway 1968) of 0.02–5 mg/kg and the range of 0.1–5 mg/kg reported for plants growing in non-serpentine soils (Freedman and Hutchinson 1981). Maximum values of Ni in urban herbage from England, Northern Ireland and Scotland exceeded these ranges.

The mean Ni concentration in urban herbage in Scotland was significantly higher than that in Wales.

Platinum (Pt)

Summary statistics are provided for each of the four countries in Table 5.23 and illustrated in Figure 5.2c.

Table 5.23 – Concentrations of Pt in urban herbage of different countries in the UKSHS (mg/kg)

Platinum	*n*	Range	Mean	Median	SD
UK	87	0.02–0.02	0.02	0.02	0.00
England	42	0.02–0.02	0.02	0.02	0.00
N. Ireland	18	0.02–0.02	0.02	0.02	0.00
Scotland	18	0.02–0.17	0.02	0.02	0.00
Wales	9	0.02–0.02	0.02	0.02	0.00

The results presented in Table 5.22 reflect the limit of detection for platinum in herbage (0.02 mg/kg). A single high value of 0.17 mg/kg was reported for a site in Scotland. Pt concentrations in urban herbage may be generally higher than the <0.001 mg/kg reported for un-mineralised soils and may lie within the range of concentrations found in 'mineralised' sites of 0–0.275 mg/kg (Rencz and Hall 1992).

Very low Pt concentrations have been reported for grass adjacent to highways in the USA. Concentrations of 0.0034–0.0077 mg/kg were reported by Helmers *et al.* (1998), while Ely *et al*. (2001) reported a range of 0.0012–0.0017 mg/kg for washed and unwashed grass samples from the verges of a heavily used (24,350 vehicles per day) toll road in Indiana.

Titanium (Ti)

Summary statistics are provided for each of the four countries in Table 5.24.

Table 5.24 – Concentrations of Ti in urban herbage of different countries in the UKSHS (mg/kg)#

Titanium	*n*	Range	Mean	Median	SD
UK	87	5–381	41.2	12.4	60.3
England	42	5–75	20.6[bc]	7.63	22.5
N. Ireland	18	5–213	48.3[b]	17.4	61.4
Scotland	18	5–381	98.7[a]	72.0	90.7
Wales	9	5–21.7	8.38[c]	5.00	5.81

Mean values in the same column followed by different letters are significantly different at p <0.05 or better.

The range of Ti concentrations in UK urban herbage was wider than in rural vegetation (Table 5.10) and higher than the Ti concentration reported for grass pasture growing on Ti-rich soils in Oregon, USA (218 mg/kg) by Mayland and Sneva (1983). Although the mean Ti concentrations in urban vegetation in all four countries lay well below this concentration, the maximum Ti concentration in Northern Ireland was very similar and the maximum Ti concentration in Scotland was higher. Herbage Ti concentrations at seven sites (one in England, three in Northern Ireland and three in Scotland) were higher than all other results and contributed high Ti concentrations to the UK statistics. It is possible that these sites represent locations that were sampled on days when inclement weather conditions resulted in slight soil contamination of herbage. The possibility that these few higher results were due to contamination of the herbage by soil is discussed in Section 5.5.

Vanadium (V)

Summary statistics are provided for each of the four countries in Table 5.25 and illustrated in Figure 5.2a.

Table 5.25 – Concentrations of V in urban herbage of different countries in the UKSHS (mg/kg)#

Vanadium	*n*	Range	Mean	Median	SD
UK	87	2.0–23.5	4.35	2.0	4.36
England	42	2.0–22.7	4.11^{b}	2.0	4.53
N. Ireland	18	2.0–10.4	3.41^{b}	2.0	2.45
Scotland	18	2.0–23.5	6.96^{a}	6.1	5.46
Wales	9	2.0–3.0	2.11^{b}	2.0	0.33

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of V concentrations in UK urban herbage was a little higher than in rural herbage (Table 5.11), with highest values in England and Scotland. A number of values were at the limit of detection for vanadium (2 mg/kg).

Zinc (Zn)

Summary statistics are provided for each of the four countries in Table 5.26 and illustrated in Figure 5.2b.

Table 5.26 – Concentrations of Zn in urban herbage of different countries in the UKSHS (mg/kg)#

Zinc	*n*	Range	Mean	Median	SD
UK	87	22.1–184	53.6	47.2	26.9
England	42	24.6–184	58.6^{ab}	50.1	32.3
N. Ireland	18	26.4–56.6	36.4^{c}	33.2	8.8
Scotland	18	35.0–103	63.9^{a}	58.8	21.0
Wales	9	22.1–64	43.7^{bc}	41.8	13.3

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of Zn concentrations in UK urban vegetation was wider than in rural vegetation (Table 5.12), but was still well within the early range of values (8–400 mg/kg) found in plants growing in uncontaminated soils (Allaway 1968). There was a greater disparity between countries in terms of Zn concentrations in urban vegetation than in rural vegetation. Mean Zn concentrations in England and Scotland were significantly higher than those in Northern Ireland.

5.3.2 Other metals in urban herbage

Tin (Sn)

Summary statistics are provided for each of the four countries in Table 5.27.

Table 5.27 – Concentrations of Sn in urban herbage of different countries in the UKSHS (mg/kg)

Tin	*n*	Range	Mean	Median	SD
UK	87	2.0–4.04	2.04	2.0	0.24
England	42	2.0–4.04	2.05	2.0	0.31
N. Ireland	18	2.0–2.00	2.00	2.0	0.00
Scotland	18	2.0–3.03	2.06	2.0	0.24
Wales	9	2.0–2.0	2.00	2.0	0.00

The range of Sn concentrations in UK urban herbage was very similar to that of rural herbage (Table 5.13) and within the early range of values (0.2–6.8 mg/kg) reported for vegetation growing on generally uncontaminated soils (Allaway 1968). As for Sn concentrations in rural soils, the range of Sn concentrations in urban herbage was highest in England, probably reflecting higher values from locations closest to mining sites in Devon and Cornwall.

Lead (Pb)

Summary statistics are provided for each of the four countries in Table 5.28 and illustrated in Figure 5.2a.

Table 5.28 – Concentrations of Pb in urban herbage of different countries in the UKSHS (mg/kg)#

Lead	*n*	Range	Mean	Median	SD
UK	87	0.95–40.20	8.65	3.95	10.5
England	42	1.06–38.70	9.79^{a}	4.39	11.1
N. Ireland	18	1.00–5.13	2.12^{b}	1.04	1.52
Scotland	18	0.95–40.20	15.4^{a}	14.9	11.9
Wales	9	1.00–11.50	2.94^{b}	1.60	3.44

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

Although the range of Pb concentrations in UK urban herbage overall was lower than in rural herbage (Table 5.14), mean Pb concentrations and standard deviations in urban herbage in England and Scotland were much higher; they were not too different in Wales and lower in Northern Ireland. These results probably reflect a range of urban site types such as those adjacent to roads with high rates of Pb deposition from exhaust fumes in the past compared with sites within parks.

Mean Pb concentrations in urban herbage, except in Scotland where mean Pb concentrations were higher, lay within the early range of concentrations (0.1–10 mg/kg) found in plants from generally uncontaminated sites (Allaway 1968). Highest maximum Pb concentrations and highest mean Pb concentrations were found in Scottish urban herbage.

5.3.3 Metalloids in urban herbage

Arsenic (As)

Summary statistics are provided for each of the four countries in Table 5.29 and illustrated in Figure 5.2a.

Table 5.29 – Concentrations of As in urban herbage of different countries in the UKSHS (mg/kg)#

Arsenic	*n*	Range	Mean	Median	SD
UK	87	0.15–7.02	1.11	0.50	1.17
England	42	0.17–7.02	1.40^{ab}	0.50	1.53
N. Ireland	18	0.15–1.80	0.60^{c}	0.50	0.34
Scotland	18	0.50–3.11	1.16^{a}	0.97	0.72
Wales	9	0.50–1.42	0.64^{bc}	0.50	0.32

Mean values in the same column followed by different letters are significantly different at $p < 0.05$ or better.

The range of As concentrations in urban herbage was a little higher than in rural vegetation (0.5–3.21 mg/kg) (Table 5.15) and higher than the 3 mg/kg reported by Porter and Peterson (1977) for plants growing in uncontaminated soils. Although the mean As concentration in all four countries was lower than this value, the maximum As concentration in England exceeded this value and the maximum As concentration in Scotland was similar.

Kabata-Pendias (2000) stated that only a limited fraction of the total amount of As in soils is easily mobile and available for uptake by plants.

5.3.4 Conclusions on heavy metals and metalloids in urban herbage

Most of the concentrations observed in UKSHS were within the ranges observed in other studies. Unlike the rural soils and herbage and also the urban soils, there was no clear relationship between significant differences in urban herbage and the corresponding urban soil. This was possibly because:

- statistical analysis was only possible on the herbage data for four metals (the remainder had many results at the limit of detection);
- uptake from soil was no longer the main pathway for contamination.

It is not possible to distinguish between the two possibilities from the UKSHS results.

5.4 Herbage from industrial locations

5.4.1 Heavy metals and metalloids in Industrial Sites

Table 5.30 summarises the mean metal/metalloid herbage concentrations from rural, urban and industrial sites in the UKSHS. The raw data for industrial herbage are presented in Appendix 7 (available as an Excel spreadsheet on the CD that accompanies UKSHS Report No. 1). The data are presented as mg/kg dry weight of herbage.

Table 5.30 – Mean concentrations of metals/metalloids in rural, urban and industrial herbage (mg/kg)

	Rural	Urban	Industrial
Arsenic	0.56	1.11**	0.86**
Cadmium	0.14	0.16	0.58*
Chromium	1.76	3.78**	2.64**
Copper	7.26	11.38**	9.45**
Lead	2.12	8.65**	15.9**
Manganese	243	206	186**
Mercury	0.073	0.086**	0.081**
Nickel	1.76	3.88**	4.36**
Platinum[1]	–	–	–
Tin	–	–	–
Titanium	11.4	41.2**	18.1**
Vanadium	2.30	4.35**	2.87*
Zinc	35.9	53.5**	75.4**

* Significant difference from rural data at $p < 0.05$

** Significant difference from rural data at $p < 0.01$

[1] No analysis performed on platinum and tin data as results all at or below LOD.

With the exception of Cd and Mn, mean metal concentrations in the herbage from urban sites were significantly higher than rural levels. All the elements except Mn showed elevated concentrations in herbage from industrial sites compared with rural sites – in some cases with significantly higher concentrations. The mean Mn concentration in industrial herbage was significantly lower then the rural mean.

In most cases, the herbage concentrations mirrored those in soil suggesting that uptake is the main pathway for contamination. Concentrations of Cr and V in urban herbage were the exception, possibly indicating that aerial deposition is more important for these two elements.

The concentration of copper reported for herbage sampled at one industrial location would be high enough to cause copper toxicity in sheep (generally > 10 mg/kg). The copper concentrations reported for samples of herbage from a second industrial location, although only half as high as the maximum reported for the first location, are still considered to be high enough to be a possible risk. High copper concentrations were also reported in herbage sampled at several other industrial locations and the same comment applies with regard to the risk of toxicity in sheep. There is also a potential toxicity risk to livestock wherever high cadmium concentrations occur in herbage. High levels of zinc possibly suggest that the herbage has evolved a tolerance to high concentrations that would normally be expected to have a phytotoxic effect.

There were some quite high copper concentrations in all the UKSHS herbage data (rural, urban and industrial). These are likely to be due to surface contamination from atmospheric deposition since root uptake does not often lead to high concentrations in the leaves.

5.5 Soil–plant concentration factors at rural, urban and industrial sites

The soil–plant concentration factors (CF) for each of the 13 inorganic elements studied in rural, urban and industrial herbage are given in Appendix 8. CF is calculated as follows:

$$\text{CF} = \frac{\text{Metal concentration in herbage}}{\text{Metal concentration in soil}}$$

Since vegetation samples in the UKSHS were dried and analysed without any other treatment, the CF gives a comparison between sites and between metals of the relative uptake of metal by herbage combined with the amount of deposition on the surfaces of leaves.

A further potential source of trace metals in herbage samples is from soil contamination. Plants do not readily take up titanium. Since Ti concentrations in soil are high (1,000–3,000 mg/kg) and concentrations in plants are low (<1 mg/kg), Ti has been used experimentally to detect soil contamination of vegetation. This approach was also used in the UKSHS.

5.5.1 Potential for soil contamination of rural herbage samples

In the UKSHS rural herbage study, all the samples (except three in Northern Ireland) had Ti concentrations <100 mg/kg indicating generally low levels of soil contamination of the herbage.

A simple Ti vegetation/soil ratio for all UK rural herbage data gives an average ratio of 0.12 (range 0.005–0.69), with the majority (22.5 per cent) of data points less than 0.2.

An examination of the coincidence of high heavy metal concentrations in herbage with the incidence of high Ti concentrations found two sites in England, two sites in Northern Ireland and two sites in Scotland where there was a pattern of high heavy metal concentrations (particularly As, Cr, Ni, Pb and V) associated with high Ti concentrations. For these six sites, it is possible that the herbage heavy metal results show some degree of soil contamination.

5.5.2 Potential for soil contamination of urban herbage samples

In the UKSHS urban herbage study, all the samples (except four in Northern Ireland and seven in Scotland) had Ti concentrations <100 mg/kg indicating generally low levels of soil contamination of the herbage.

Ti vegetation/soil ratios for all UK urban data have an average ratio of 0.123 (range 0.002–0.688), with the majority (20.7 per cent) of data points less than 0.2.

An examination of the coincidence of high heavy metal concentrations in urban herbage with the incidence of high Ti concentrations found two sites in England, one site in Northern Ireland, one site in Scotland and one site in Wales where there was a pattern of high heavy metal concentrations (particularly As, Cr, Hg, Ni, Pb and V) associated with high Ti concentrations. For these five sites, it is possible that the herbage heavy metal results show some degree of soil contamination.

5.5.3 Potential for soil contamination of herbage samples from industrial sites

In herbage from industrial sites in the UKSHS, Ti vegetation/soil ratios give mean values of 0.098 (incinerator sites), 0.043 (power stations) and 0.055 (mineral industry sites). The respective ranges of Ti CF values are 0.004–0.564, 0.004–0.238 and 0.021–29.4. These results indicate that there could be problems with soil contamination of herbage samples collected from mineral industry sites.

A closer inspection of mineral industry sites indicated that only for one site in Scotland was there a coincidence of high heavy metal concentrations in the herbage (As, Cr, Mn, Ni, Pb and V) as well as a high concentration of Ti. Inspection of non-ferrous metal sites also indicated that, at one site in England and one site in Wales, there was a coincidence of high heavy metal concentrations in herbage with a high concentration of Ti. At the Welsh site, elevated concentrations of As, Cd, Cr, Cu, Mn, Ni, Pb, V and Zn were encountered along with high levels of Ti.

The following section provides a brief assessment of CF values across metals and across rural, urban and industrial sites. It does not discuss CF values for each metal individually. Since Pt concentrations in soil and herbage were identical, CF values for Pt are ignored.

5.5.4 Concentration factors from rural and urban sites

Metals showing the highest CF values in all rural and urban data are Cd, Cu, Mn, Hg, Pt, Sn and Zn (Appendix 8).

Metals showing the lowest CF values in rural and urban data are Pb, Ti and V.

These results indicate that the trace metals studied in the UKSHS that are essential for plant growth (Cu Mn Ni V Zn) are not necessarily taken up in the greatest amounts by plants. The results also confirm that plants do not readily take up Pb, Ti and V.

Table 31 presents the correlation coefficients comparing soil and herbage metal concentrations for all 13 metals/metalloids in rural and urban sites of the UKSHS.

The correlation results indicate that there is a clear relationship between soil and herbage concentration of Ni and Ti at both rural and urban sites. There are also significant relationships at rural sites between soil and herbage concentrations of Cr and Cu, and at urban sites between Cd, Sn and Zn. The value of 1 for Pt in urban soils is ignored.

Interesting results from the rural and urban CF datasets are as follows:

- The higher mean and variance of CF for Mn in Scottish rural data parallel the higher mean and variance of rural soil Mn concentrations. This indicates one of three things:
  (i) that vegetation uptake was higher on soils with higher Mn concentrations;
  (ii) that there had been more foliar Mn deposition on sites with higher soil Mn concentrations;
  (iii) that soil contamination had occurred (less soil of high Mn concentration would be required to elevate rural herbage Mn concentrations).

- The higher rural soil Cr concentrations in Northern Ireland are not paralleled by significantly higher Cr CF values in Northern Ireland. However, higher rural soil Ni concentrations in Northern Ireland are paralleled by significantly higher Ni CF values in Northern Ireland. These two findings indicate that there is a difference in uptake of Cr and Ni, with higher uptake of Ni on Ni-rich soils.

Table 5.31 – Correlation coefficients for the concentrations of 13 metals/metalloids in soil and herbage from rural and urban locations

	Rural correlation coefficient	**Urban correlation coefficient**
Arsenic	0.132	0.111
Cadmium	0.144	0.523***
Chromium	0.278**	0.018
Copper	0.301**	0.092
Lead	0.083	0.184
Manganese	0.144	0.182
Mercury	0.120	0.189
Nickel	0.341***	0.219**
Platinum	–0.003	1.00
Tin	–0.015	0.412***
Titanium	0.195*	0.295**
Vanadium	0.086	0.086
Zinc	0.034	0.428***

Note: *p* represents the probability associated with rejection of the null hypothesis in correlation analysis. A value of *p* = 0.001 indicates that on 0.001 per cent of occasions, the null hypothesis that there is no relationship between metal concentrations in soil and herbage will be rejected when in fact it is true. This equates to once in 100,000 times.

*** *p* = 0.001
** *p* = 0.01
* *p* = 0.05

CFs from industrial sites

No one trace metal showed consistently low CF values over all industry types (Appendix 9). This could be due to the difference between uptake from trace metals derived from rock/soil and those from atmospheric deposition.

CF means and ranges for all trace metals at mineral industry sites were higher and more variable than at other types of industrial sites. Particularly high ranges of CF values were observed for Cr, Pb, Mn, Ni, Ti and V at mineral industry sites. CF means and ranges were also high for Cr, Mn, Hg and Ti at non-ferrous metal industry sites. Low CF values for As, Pb, Ti and V were found at incinerator and power station sites, but much higher values (>1) were found at mineral industry sites. This could indicate either higher levels of uptake of these metals from soils at mineral industry sites or more deposition of these trace metals directly onto foliage at mineral industry sites.

Comment on CFs

It is surprising that Appendix 8 contains instances of higher mean CF values for Hg, Pt, Sn and Zn than those for Cd, which is acknowledged as being the element with the highest soil–plant concentration factor (at least through uptake by the roots). The relatively high CF values for Hg, Pt, Sn, Zn and Mn are an indication of atmospheric deposition onto foliage and not necessarily accumulation through the roots. This would be expected with Pt from vehicle exhausts.

6 Summary and recommendations

This section of the report provides a brief summary of the UKSHS results on heavy metals/metalloids found in rural, urban and industrial soils and herbage. Key findings are highlighted and recommendations made for further work.

6.1 Heavy metals/metalloids in rural, urban and industrial soils

6.1.1 Rural soils

- The majority of trace metals (Cd, Cr, Cu, Hg, Ni, Zn, Pb) in rural soils were present in concentrations within the ranges reported in previous surveys of generally uncontaminated UK soils.

- There were significant geographical differences between the four countries:
  - Mean concentrations of Cu were significantly higher in Northern Ireland than in the other three countries.
  - Ti was significantly higher in Northern Ireland and Scotland than in England and Wales.
  - Conversely, Pb and As were significantly lower in Northern Ireland and Scotland.

- A number of significant correlations exist between soil characteristics (pH and soil organic matter) and trace metal concentrations. Over the whole of the UK, there are significant positive correlations between pH and Zn and between soil organic matter and Hg. More significant correlations are seen in the datasets for each of the four countries when they are analysed individually.

- A number of significant correlations exist among soil trace metals. Using only the overall UK dataset, the most significant positive correlations were observed between:
  - Zn with As, Cd, Cr, Cu and Pb;
  - Cr with Cu, Ni, Ti, V and Zn;
  - Cu with Mn, Hg, Ni, Ti and Zn.

6.1.2 Urban soils

- The range of concentrations of several trace metals (Cd, Cu, Hg, Ti, Zn) in urban soils was higher than in rural soils. The concentration ranges of Cr, Mn, Ni, V, Sn, Pb, As in urban soils were lower than in rural soils.

- As for rural soils, there were some clear geographical variations in urban soil concentrations:
  - Cr, Ti and V were significantly higher in Northern Ireland than in England and Wales.
  - Ni was significantly higher in Northern Ireland than in the other three countries.
  - Conversely, As was lower in Northern Ireland urban soils than in the other three countries.
  - Overall, the trends in urban soils mirrored those in rural soils.

6.1.3 Industrial soils

- Mean concentrations of Cu, Pb, Hg, Ni, Sn and Zn were significantly elevated at both urban and industrial sites compared with the rural data. On average, urban and industrial soil concentrations of Cu, Pb, Hg and Sn were 2–3 times those in rural soils.

- Concentrations of As, Cd and V are only significantly greater than background in industrial soils. Cr concentrations were not significantly different in rural and urban soils.

- No overall pattern of heavy metal concentrations with distance downwind of industrial sites was seen across any of the industries where samples were collected. No single type of industrial **process** showed any clear pattern upwind and downwind of soil metal concentrations. Certain industrial **sites** showed decreasing patterns of soil trace metals downwind.

6.1.4 Little studied elements in industrial soils

- Few elements appeared to be present in concentrations considered to be high compared with those found in soils worldwide.

- Five elements (Sb, Bi, Se, Mo and W) were found to be present in three or more UK industrial soils at concentrations greater than the generally reported range of concentrations in soils worldwide.

6.2 Heavy metals/metalloids in rural, urban and industrial herbage

6.2.1 Rural herbage

- The ranges of Cd, Hg, Zn and Sn concentrations in rural herbage were well within those found in other studies of trace metals in vegetation from uncontaminated sites.

- Statistical analysis of the differences in rural herbage results between the four countries was performed only for four determinands (Cu, Ni, Mn, Zn) because many results for the other elements were at their limit of detection.
  - Cu and Ni concentrations in rural herbage were significantly higher in Northern Ireland. For Cu, this mirrors the results for rural soil.
  - For Mn and Zn, no clear patterns were observed.

- There is the possibility that herbage samples from two sites in each of England, Scotland and Northern Ireland could have suffered some degree of soil contamination.

6.2.2 Urban herbage

- Mean concentrations of Cu, Pb, Ni, Ti and Zn in the herbage from urban sites were significantly higher than rural levels.

- In most cases, the herbage concentrations mirrored those in soil, suggesting that uptake is the main pathway for contamination. Concentrations of Cr in urban herbage were the exception, possibly indicating that aerial deposition is more important for this element.

- Ranges of Cu, Ti, V, Zn and As concentrations in urban soils were higher than ranges in rural soils, while ranges of Cd, Cr, Mn, Ni and Pb concentrations in urban soils were lower than ranges in rural soils.

- The ranges of concentrations of Cd, Cu, Hg, Zn and Sn in urban herbage were within those reported in previous studies of heavy metal concentrations in vegetation, while the ranges of Cr, Ni and Pb concentrations in urban herbage were higher than those previously reported.

- There is the possibility that herbage samples from two sites in England and one site in each of Scotland, Northern Ireland and Wales could have suffered some degree of soil contamination.

6.2.3 Herbage from industrial sites

- Cu, Pb, Ni, Ti and Zn concentrations were significantly higher in industrial herbage compared to rural herbage.

- The majority of industrial sites had herbage metal concentrations within the range of concentrations in rural soils and in generally uncontaminated soils in previous studies.

- There was no overall pattern of decreasing concentration of trace metals in herbage downwind of industrial sites.

- There is the potential that herbage from one mineral site in Scotland, one non-ferrous metal site in England and one non-ferrous metal site in Wales could have suffered some degree of soil contamination.

6.3 Recommendations for further work

A number of surprising results were found in the UKSHS data. These provide topics for further work.

- High concentrations of Cu in rural soils and Cr in rural herbage in Northern Ireland should be investigated. Similarly, high Cr concentrations in urban herbage in Scotland may warrant further investigation.

- Industrial sites identified as having elevated soil concentrations of little studied elements (studied using semi-quantitative techniques) – particularly Ce, Gd, Sb, Bi, Se, Mo and W – should be the focus for more detailed quantitative soil analysis.

- The elevated concentrations of Se in rural soils in Scotland and Wales should be studied in more detail using quantitative techniques.

- The determinations of Pt in both soil and herbage resulted in very few samples showing concentrations higher than the detection limit of the analytical technique. Further work is required to improve the analysis and to lower the detection limit to that obtainable in other studies such as Helmers *et al.* (1998). Refinement of the technique should elucidate further patterns in Pt soil and herbage concentrations across the UK. It may be appropriate to include the other platinum group metals (Pd and Rh) in a more detailed study.

- Relatively little data have previously been collected on Pt, Sn or V in soils or vegetation in the UK. Collation of data residing in unpublished databases, for example in ADAS databases or within the files of regional offices of regulatory agencies (Environment Agency, SEPA, etc.) would help to corroborate current UKSHS results for these trace metals.

- Collaboration with the British Geological Survey to identify geochemically-related patterns in its geographical (GIS) database of trace metals in soils would help to remove 'naturally'-occurring instances of high trace metal concentrations from the UKSHS soil database. This would allow targeting of high concentration sites where anomalous results are due to contamination and not inherited from parent rocks.

The UKSHS database also provides an opportunity for more detailed study and analytical interpretation. The following preliminary suggestions are made for further data interpretation:

- Identify and subject to a more detailed inspection individual sites where consistently high soil or herbage heavy metal concentrations were found across the suite of metals studied or in all sub samples. This should be followed up with a positive identification of the source or cause of contamination.

- Examine the correlation between incidences of high concentrations in industrial soils of the 13 heavy metals/arsenic discussed in Section 4.3 with incidences of high concentrations of the little studied elements discussed in Section 4.4.

- Using the rural soils dataset, assess in more detail the relationship between soil properties, particularly soil pH and soil organic matter content, and the incidence of high concentrations of soil heavy metals. It would also be worth checking the detailed data in European Soil Bureau (2000) for trends in metal concentrations with both pH and soil organic matter content.

- Compare results from the semi-quantitative determination of elements in industrial soils with the results of radionuclide determinations (particularly for Cs, Sr, Th and U).

List of abbreviations

CEC	cation exchange capacity
CF	soil-plant concentration factor
JURUE	Joint Unit for Research on the Urban Environment, Aston University
LOD	limit of detection
ICPMS	inductively coupled plasma mass spectrometry
NAS	National Academy of Sciences
ND	not detected
NLS	National Laboratory Service
OM	organic matter
SD	standard deviation
SEPA	Scottish Environment Protection Agency
UKAS	United Kingdom Accreditation Service
UKSHS	UK Soil and Herbage Pollutant Survey
UoL	University of Liverpool

References

Abbott J A, Baker S J, Coleman, P J, Dyke P H, Haines, J and Watterson J D, 1997 *A study of dioxins and trace metals in soil around four municipal waste incinerators in Hampshire. Part 2: Trace metals*. Report prepared by AEA Technology for the Environment Agency. Report HO-7/97-210-C-AZLN. Bristol: Environment Agency.

Adriano D C, 2001 *Trace elements in terrestrial environments* (2nd edn.). New York: Springer.

Allan J, Darlington S T, Hawkings C I and Eduljee G H, 1999 *A baseline soil survey in the south Dudley area*. Report for contract HOCO-300. Bristol: Environment Agency.

Allaway W H, 1968 *Agronomic controls over the environmental cycling of trace elements*. Advances in Agronomy, **20**, 235-274.

Alloway B J 1995 *Cadmium*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 122-151. London: Blackie Academic and Professional.

Alloway B J, Zhang P, Mott C, Chambers B J, Nicholson F A, Smith S R, Carlton-Smith C and Duncan A 1998 *The vulnerability of soils to pollution by heavy metals*. Final Report and Appendix to MAFF Contract OC 9325 [unpublished].

Archer FC, 1963 *Trace elements in some Welsh upland soils*. Journal of Soil Science, **14**, 144-148.

Archer F C and Hodgson I H, 1987 *Total and extractable trace element contents of soils in England and Wales*. Journal of Soil Science, **38**, 421-431.

Asami T, 1988 *Environmental pollution by beryllium in Japan*. In Proceedings of Contaminated Soil '88*,* edited by K Wolf K, W J van den Brink and F J Colon, 261. Dordrecht: Kluwer Academic.

Asami T, Yoshimo A, Kubota M and Gotoh S, 1990 *Background level of indium and gallium in soil with special reference to pollution of the soils from zinc and lead smelters.* Zeitschrift für Pflanzenernährung Bodenkunde, **153**, 257.

Ashmore M, Colgan A, Farago M, Fowler D, Hall J, Hill M, Jordan C, Lawler A, Lofts S, Nemitz E, Pan G, Paton G, Rieuwerts J, Thornton I and Tipping E, 2000 *Development of a critical load methodology for toxic metals in soils and surface waters: Stage II.* EPG 1/3/144: Final Report; Part 1. London: Department of the Environment, Transport and the Regions.

Baker D E and Senft J P, 1995 *Copper*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 179-205. London: Blackie Academic and Professional.

Berrow M L and Burridge J C, 1979 *Sources and distribution of trace elements in soils and related crops.* In Proceedings of the International Conference on Management and Control of Heavy Metals in the Environment (London, 1979). Edinburgh: CEP Consultants.

Berrow M L and Reaves G A, 1984 *Background levels of trace elements in soils*. In Proceedings *of* the International Symposium on Environmental Contamination (London, 1984), 333-340.

Bhat P N and Pillai K C, 1997 *Beryllium in environmental air, water and soil.* Water, Air and Soil Pollution, **95**, 133-146.

Bini C, Dall'Aglio M, Ferretti O and Gragnani R, 1988 *Background levels of microelements in soils of Italy*. Environmental Geochemistry and Health, **10**, 35.

Black H I J, Garnett J S, Ainsworth G, Coward P A, Creamer R, Ellwood S, Horne J, Hornung M, Kennedy V H, Monson F, Raine L, Osborn D, Parekh N R, Parrington J, Poskitt J M, Potter E, Reeves N, Rowland A P, Self P, Turner S, Watkins P, Woods C and Wright J, 2002 *MASQ: Monitoring and assessing soil quality in Great Britain.* Countryside Survey Module 6: Soils and Pollution. R&D Technical Report E1-063/TR. Bristol: Environment Agency.

Borowska K, Malczyk P and Kędzia W, 1994 *The distribution of total selenium in arable and forest soils of Bydgoszcz voivodship*. In Polish Academy of Sciences seminar on *Arsenic and Selenium in the Environment – Ecological and Analytical Problems* (Warsaw, 1993), edited by A Kabata-Pendias and B Szteke).

Bowen H J M, 1979 *Environmental Chemistry of the Elements* New York: Academic Press.

Braithwaite R D, 1995 *The Prioritisation of Potentially Polluting Elements for the Investigation of Contaminated Land*. Unpublished MSc Thesis, University of Derby.

Breeze V G, 1973 *Land reclamation and river pollution problems in the Croal Valley caused by waste from chromate manufacture*. Journal of Applied Ecology, **10**, 513-525.

Bromfield S M, 1958a *The solution of substances released from soil and from the root of oats and vetch in relation to Mn availability*. Plant and Soil, **10**, 147-160.

Bromfield S M, 1958b *The properties of a biologically formed manganese oxide, its availability to oats and its solution by root washings*. Plant and Soil, **9**, 325-337.

Brooks R R, 1987 *Serpentine and its Vegetation. A Multidisciplinary Approach*. Portland, OR: Dioscorides Press.

Cary E E, Allaway W H and Olson O E, 1977 *Control of chromium concentrations in food plants. I. Absorption and translocation of chromium in plants. II. Chemistry of chromium in soils and its availability to plants*. Journal of Agricultural and Food Chemistry, **25**, 300-305.

Chapman H D, 1972 Editor *Diagnostic Criteria for Plants and Soils*. Riverside, CA: University of California.

Chattopadhyay A and Jervis R E, 1974 *Multi-element determination in market-garden soils by instrumental photon activation analysis*. Analytical Chemistry, **46**, 1630.

Crecelius E A, Johnson C J and Hofer G C, 1974 *Contamination of soils near a copper smelter by arsenic, antimony and lead*. Water, Air and Soil Pollution, **3**, 337-342.

Culbard E B and Johnson L R, 1984 *An assessment of arsenic in house dust and garden soils from SW England and their implications for human health*. In Proceedings of the International Symposium on Environmental Contamination (London, 1984), pp. 276–281. Edinburgh: London: CEP Consultants.

Dalenberg J W and van Driel W, 1990 *Contribution of atmospheric deposition to heavy metal concentrations in field crops*. Netherlands Journal of Agricultural Science, **38**, 367-379.

Davies B E and Ginnever R C, 1979 *Trace metal contamination of soils and vegetables in Shipham, Somerset*. Journal of Agricultural Science, **93**, 753-756.

Edwards R N Lepp, N W and Jones K C, 1995 *Other less abundant elements of potential environmental significance*. In Heavy Metals in Soils (3rd edn.) (ed. B J Alloway), Chapter 14. London: Blackie Academic and Professional.

Ely J C, Neal C R, Kulpa C F, Schneegurt M A, Seidler J A and Jain J C, 2001 *Implications of platinum-group element accumulation along US roads from catalytic converter attrition*. Environmental Science and Technology, **35**, 3816-3822.

Erdman J A, Shacklette H T and Keith J R, 1976 *Elemental composition of selected native plants and associated soils from major vegetation-type areas in Missouri*. US Geological Survey Professional Paper 954c. Washington DC: US Geological Survey.

European Soil Bureau, 2000 *Heavy metal (trace element) and organic matter contents of European soils. Results of preliminary evaluation for four Member States (F,DK,G,UK)*. Ispra, Italy: European Commission, Joint Research Centre.

Farago M E and Cole M M, 1988 *Nickel and plants*. In Metal Ions in Biological Systems. Volume 23: Nickel and its Role in Biology (ed. H Sigel and A Sigel), pp. 47-90. New York: Marcel Dekker.

Farago M E, Kavanagh P, Blanks R, Kelly J, Kazantzis G, Thornton I, Simpson P R, Cook J M, Delves H T and Hall G E M, 1998 *Platinum concentrations in urban road dust and soil, blood and urine in the United Kingdom*. Analyst, **123**, 451-455.

Fergusson J, 1990 *The Heavy Elements: Chemistry, Environmental Impact and Health Effects*. Oxford: Pergammon Press.

Frank R, Stonefield K I and Suda P, 1979 *Metals in agricultural soils of Ontario*. Canadian Journal of Soil Science, **59**, 99-103.

Freedman B and Hutchinson TC, 1981 *Sources of metal and environmental contamination of ecosystems*. In Effects of Heavy Metal Pollution on Plants. Volume 2: Metals in the Environment (ed. N W Lepp), pp. 35-94. London: Applied Science.

Furr A K, Parkinson T F, Bache C A, Gutenmann W H, Pakkala I and Lisk D J, 1980 *Multielement absorption by crops grown on soils amended with municipal sludge ashes*. Journal of Agricultural Food Chemistry, **28**, 660-662.

Godo G H and Reisenauer H M, 1980 *Plant effects on soil manganese availability*. Soil Science Society of America Journal, **44**, 993-995.

Gough LP, Severson RC and Shacklette HT, 1988 *Element concentrations in soils and other surficial materials of Alaska*. US Geological Survey Professional Paper 1458. Washington DC: US Geological Survey.

Govindaraju K, 1994 *Compilation of working values and sample description for 383 geostandards*. Geostandards Newsletter, **18**, 1.

Gröβmann G and Wüstermann M, 1992 *Belastungenin Haus und Kleingarten durch anorganische und organische Stoffe mit Schadstoffpotential. Forschungsbericht* 1160969, Umweltforschungsplan des Bundesministers fur Umwelt, Naturschutz und Reactorsicherheit.

Haidouti C, Skarlou V and Tsouloucha F, 1985 *Mercury contents of some Greek soils*. Geoderma, **35**, 251-256.

Hakanson L, Nilsson A and Andersson T, 1990 *Mercury in the Swedish mor layer – linkages to mercury deposition and sources of emission.* Water, Air and Soil Pollution, **50**, 311-329.

Healy W B, 1968 *Ingestion of soil by dairy cows.* New Zealand Journal of Agricultural Research 11, 487-499.

Helmers E, Schwarzer M and Schuster M, 1998 *Comparison of palladium and platinum in environmental matrices: palladium pollution by automobile emissions.* Environmental Science Pollution Research, **5**, 44-50.

Higney E, Olive V, MacKenzie A B and Pulford I D, 2002 *Isotope dilution ICP-MS analysis of platinum in road dusts from west central Scotland*. Applied Geochemistry, **17**, 1123-1129.

Holmgren C G S, Meyer N, Chaney R L and Daniels R B, 1993 *Cadmium, lead, zinc, copper and nickel in agricultural soils of the United States*. Journal of Environmental Quality*,* **22**, 335-348.

Horovitz C T, 2000 Editor *Biochemistry of Scandium and Yttrium, Part 1: Physical and Chemical Fundamentals.* New York, Boston, London and Moscow: Kluwer Academic/Plenum Publishers.

Isenbeck M, Schröter J, Taylor T, Fic M, Pekdegen A and Matthess G, 1987. *Adsorption/desorption and solution/precipitation behaviour of cadmium as influenced by the chemical properties of ground water and aquifer material*. Meyniana, **39**, 7-21.

Jones S D and Doner H E, 1997 *X-ray fluorescence microprobe analysis of a contaminated soil.* Berkeley, CA: University of California.

Jones K C, Davies B A and Peterson P J, 1986 *Silver in Welsh soils: physical and chemical distribution studies*. Geoderma, 37, 157-174.

Jones K C, Lepp N W and Obbard J P, 1995 *Other metals and metalloids*. In Heavy Metals in Soils (3rd edn.) (ed. B J Alloway), pp. 280-321. London: Blackie Academic and Professional

Kabata-Pendias A, 1995 *Biogeochemistry of lithium*. In Proceedings of International Symposium on Lithium in the Trophic Chain Soil–Plant–Animal–Man (Warsaw, 1995), 9.

Kabata-Pendias A, 2000 *Trace Elements in Soils and Plants* (3rd edn.). Boca Raton, FL: CRC Press. Kabata-Pendias A and Wiacek K, 1985 *Excessive uptake of heavy metals by plants from contaminated soil*. Soil Science Annals, **36**, No. 4, 33.

Kabata-Pendias A and Pendias H, 1999 *Biogeochemistry of Trace Elements* (2nd edn.). Warsaw: Wyd. Nauk PWN

Kadunas V, Budavičius R, Gregorauskiené V, Katinas V, Kliuugiene E, Radzevicius A and Taraskievicius R, 1999 *Geochemical Atlas of Lithuania*. Vilnius: Geological Institute.

Kick H, Bürger H and Sommer K, 1980 *Gesamthalte an Pb, Zn, Sn, As, Cd, Hg, Cu, Ni, Cr und Co in landwirtschaftlich und gärtnerisch genutzten Böden Nordrhein-Westfalensi.* Landwirtschaftliche Forschung, **33**, 12.

Koljonen T, 1992 Editor *The Geochemical Atlas of Finland, Part 2: Till*. Espoo: Geological Survey of Finland.

Koons R D and Helmke P A, 1978 *Neutron activation analysis of standard soils*. Soil Science Society of America Journal, **42**, 237.

Korcak R F and Fanning D S, 1985 *Availability of applied heavy metals as a function of type of soil material and metal source*. Soil Science, **140**, No. 1, 23-34.

Kubota J, 1977 *Molybdenum status of United States soils and plants*. In Molybdenum in the Environment (ed. W R Chappell and K K Peterson), pp. 555-581. New York: Marcel Dekker.

Lahann R W, 1976 *Molybdenum hazard in land disposal of sewage sludge*. Water, Air and Soil Pollution, **6**, 3-8.

Larsen EH, Moseholm L and Neitson MM, 1992 *Atmospheric deposition of trace elements around point sources and human health risk assessment. II Uptake of arsenic and chromium by vegetables grown near a wood preservation factory*. Science of the Total Environment, **126**, 263-275.

Laul J C, Weimer W C and Rancitelli L A, 1979 *Biogeochemical distribution of rare earths and other trace elements in plants and soils.* In Origin and Distribution of the Elements, Volume 11 (ed. L H Ahrens), pp. 819. Oxford: Pergamon Press.

Lindberg S E, Jackson D R, Huckabee J W, Janzen S A, Levin M J and Lund J R, 1979 *Atmospheric emission and plant uptake of mercury from agricultural soils near the Almaden mercury mine*. Journal of Environmental Quality, **8**, No. 4, 572-578.

Linde M, Bengtsson H and Oborn I, 2001 *Concentrations of heavy metals in urban soils in Stockholm, Sweden*. Water, Air and Soil Pollution: Focus **1,** No. 3-4, 83-101.

Lis J and Pasieczna A, 1995 *Geochemical Atlas of Poland. 1:2 500 000.* Warsaw: PIG.

Logan P G, 1985 *Thallium Uptake and Transport in Plants*. Unpublished PhD Thesis, Council for National Academic Awards.

Loneragan J F, 1975 *Trace Elements in Soil-Plant-Animal Systems.* London: Academic Press.

Lustig S, Zang S, Michalke B, Schramel P and Beck W, 1996 *Transformation behaviour of different platinum compounds in clay-like soil: speciation investigations*. Science of the Total Environment, **188**, 195-204.

Lustig S, Zang S, Michalke B, Schramel P and Beck W, 1997 Platinum *determination in nutrient plants by inductively coupled plasma mass spectrometry with special respect to the hafnium oxide interference*. Fresenius Journal of Analytical Chemistry, **357**, No. 8, 1157-1163.

MacLean A J, 1974 *Mercury in plants and retention of mercury by soils in relation to properties and added sulphur*. Canadian Journal of Soil Science, **54**, 287-292.

Malgin M A and Puzanov A W, 1995 *Mercury in soils and in above-soil air of Altay-Sayanskoy mountain region.* Applied Achievements of Chemistry for Sustainable Development, **3**, 161.

Markert B and Lieth H, 1987 *Element concentration cadasters in a Swedish biotope*. Fresenius Zeitschrift für Analytische Chemie, **327**, 716-718.

Marschner H, 1993 *Zinc uptake from soils.* In Zinc in Soils and Plants (ed. A D Robson), pp.59-77. Dordrecht: Kluwer Academic Publishers.

Martin M H and Coughtrey P J, 1987 *Cycling and fate of heavy metals in a contaminated woodland ecosystem.* In Pollutant Transport and Fate in Ecosystems (ed. P J Coughtrey, M H Martin and M H Unsworth), pp 319-336. Special Publication No 6 of the British Ecological Society. Oxford: Blackwell Scientific.

Mayland H F and Sneva F A, 1983 *Effect of soil contamination on the mineral composition of forage fertilised with nitrogen*. Journal of Range Management, **36**, No. 3, 286-288.

Mayland H F, Florence A R, Rodenau R C, Lazar V A and Turner H A, 1975 *Soil ingestion by cattle on semiarid range as reflected by titanium analysis of faeces*. Journal of Range Management, **28**, No. 6, 448-453.

McBride M B, 1994 *Environmental Chemistry of Soils*. Oxford: Oxford University Press.

McGrath S P, 1995 *Chromium and nickel*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 152-178. London: Blackie Academic and Professional.

McGrath S P and Loveland P J, 1992 *The Soil Geochemical Atlas of England and Wales*. London: Blackie Academic and Professional.

Ministry of Agriculture, Fisheries and Food (MAFF), 1982 *Survey of arsenic in food*. Lond: HMSO.

Mitchell R L, 1964 *Trace elements in soils,* In Chemistry of the Soil (2nd. edn.) (ed. F E Bear), Chapter 8. New York: Reinhold Publishing.

Mitchell R L and Reith J W S, 1966 *Lead content of pasture herbage*. Journal of the Science of Food and Agriculture, **17**, 437-440.

Moir A M and Thornton I, 1990 *Lead and cadmium in urban allotment and garden soils and vegetables in the United Kingdom*. Environmental Geochemistry and Health, **11**, No. 3-4, 113-119.

Motuzova G and Pershikova B, 1999 *Cadmium in the soils of the Primorye territory of Russia and its migration ability*. In Proceedings of a Symposium on Cadmium in the Environment – Ecological and Analytical Problems (Warsaw, 1999), 6.

Mukherjee A B, 1997 *The use and release of silver in Finland*. The Finnish Environment 1997, FE33. Helsinki: Finnish Environment Institute.

National Academy of Sciences (NAS), 1977 *Platinum-group Metals*. Washington DC: National Academy of Sciences.

Neilsen F H, 1997 *Beyond copper, iodine, selenium and zinc: other elements that will be found important in human nutrition by the year 2000*. In Trace Elements in Man and Animals – 9 (TEMA 9). Proceedings of the Ninth international Symposium on Trace Elements in Man and Animals, edited by P W F Fischer, M R L'Abbé, K A Cockell and R S Gibson. Ottawa: National Research Council of Canada Press.

Nicholson F A, Smith S R, Alloway B J, Carlton-Smith C and Chambers B J, 2003 *An inventory of heavy metals inputs to agricultural soils in England and Wales*. Science of the Total Environment, **311**, 205-219.

O'Neil P, 1995 *Arsenic*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 107-121. London: Blackie Academic and Professional.

Padzik A and Wlodek S, 1979 *Beryllium contamination in the rural and industrial areas in Poland* [Polish; English abstract]. Roczniki Państwowego Zakladu Higieny, 30, 397-403.

Pieri de LA, Buckley W T and Kowalenko C G, 1996 *Micronutrient concentrations of commercially grown vegetables and soils of the Lower Fraser Valley of British Columbia*. Canadian Journal of Soil Science, **76**, 173-182.

Porter E K and Peterson P J, 1977 *Arsenic tolerance in grasses growing on mine waste*. Environmental Pollution, **14**, 255-265.

Presant E W, 1971 *Geochemistry of iron, manganese, lead, copper, zinc, antimony, silver, tin and cadmium in the soils of the Bathurst area, New Brunswick*. Bulletin of the Geological Survey Canada, **174**, 1-14.

Ravindra K, Bencs L and Van Grieken R, 2004 *Review: platinum group elements in the environment and their health risk*. Science of the Total Environment, **318**, 1-43.

Reaves G A and Berrow M L, 1984 *Total copper contents in Scottish soils*. Journal of Soil Science*,* **35**, 583-592.

Reimann C, Siewers U, Tarvainen T, Bityukova L, Eriksson J, Gliucis A, Gregorauskiene V, Likashev V K, Matinina N N and Pasieczna A, 2003 Editors *Agricultural Soils in Northern Europe: A Geochemical Atlas.* Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung (Nägelle u. Obermiller).

Rencz A N and Hall G E M, 1992 *Platinum group elements and Au in Arctic vegetation growing on Gossans, Keewatin District, Canada*. Journal of Geochemical Exploration, **43**, 265-279.

Ross S M, 1994 *Retention, transformation and mobility of toxic metals in soils.* In Toxic Metals in Soil-Plant Systems (ed. S M Ross), pp. 64-152. Chichester: John Wiley and Sons.

Ryglewicz J, 1988 *Toxic trace elements in soil-plant system*. In Trace Elements and Toxic Substances in the Environment, Dum techniky, ČSVTS, Usti and Labem, 107.

Schafer J, Eckhardt J D, Berner Z A and Stobern D, 1999 *Time-dependent increase of traffic-emitted platinum-group elements (PGE) in different environmental compartments*. Environmental Science and Technology, **33**, 3166-3170.

Schalscha E B, Morales M and Pratt P F, 1987 *Lead and molybdenum in soils and forage near an atmospheric source*. Journal of Environmental Quality, **16**, 313-315.

Schwartz C, Fetzer K D, Kubiniok J and Morel J L, 2000 *Availability of pollutants in garden soils*. In Proceedings of the First International Conference on Soils of Urban, Industrial, Traffic and Mining Areas (Essen, Germany, 2000), Volume II, edited by W Burghardt and C Domauf, 485-490.

Shacklette H T and Boerngen J G, 1984 *Element concentrations in soils and other surficial materials of the conterminous United States*. US Geological Survey Professional Paper 1270.

Shacklette H T, Erdman J A and Harms T F, 1978 *Trace elements in plant foodstuffs*. In Toxicity of Heavy Metals in the Environment, Part 1 (ed. F W Oehme), pp. 25-37. New York: Marcel Dekker.

Shtangeeva I, 2005a *Scandium.* In Trace and Ultratrace Elements in Plants and Soil (ed. I Shtangeeva), pp. 223-248. Southampton, Boston: WIT Press.

Shtangeeva I, 2005b *Thorium,* In Trace and Ultratrace Elements in Plants and Soil (ed. I Shtangeeva), pp. 323-348. Southampton, Boston: WIT Press.

Slingsby D R and Brown D H, 1977 *Nickel in British serpentine soils.* Journal of Ecology, **65**, 597-618.

Smith I G and Carson B L, 1977a *Trace Metals in the Environment*. Volume1. Ann Arbor, MI: Ann Arbor Scientific Publications.

Smith I G and Carson B L, 1977b *Trace Metals in the Environment.* Volume 2. Ann Arbor, MI: Ann Arbor Scientific Publications.

Smith K A and Paterson J E, 1995 *Manganese and cobalt*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 224-244. London: Blackie Academic and Professional.

Steinnes E, 1995 *Mercury*. In Heavy Metals in Soils (2nd edn.) (ed. B J Alloway), pp. 245-259. London: Blackie Academic and Professional.

Steinnes E and Andersson E M, 1991 *Atmospheric deposition of mercury in Norway – temporal and spatial trends*. Water, Air and Soil Pollution, **56**, 391-404.

Sterckeman T, Douay F, Proix N, Fourrier H and Perdrix E, 2002 *Assessment of the contamination of cultivated soils by eighteen trace elements around smelters in Northern France.* Water, Air and Soil Pollution, **135**, 173-194.

Stoeppler M, 1991 *Cadmium.* In Metals and their Compounds in the Environment: Occurrence, Analysis and Biological Relevance (ed. E Merian), pp. 803-851. Weinham, Germany: VCH.

Strzelecki R, Wolkowicz S, Szewczyk J and Lewandowski P, 1994 *Radioecological Maps of Poland, Part II,* Warsaw: Polish Geological Institute.

Thornton I and Farago M, 1997 *The geochemistry of arsenic*. In Arsenic Exposure and Health Effects (ed. C O Abernathy, R L Calderon and W R Chappell), pp. 1-16. London: Chapman & Hall.

Thornton I, Davies D J A, Watt J M and Quinn M J, 1990 *Lead exposure in young children from dust and soil in the United Kingdom*. Environmental Health Perspectives, **89**, 55-60.

Tjell J C, Hovmand E M F and Mosbaek H, 1979 *Atmospheric lead pollution of grass grown in a background area in Denmark*. Nature (London), **280**, 425-426.

Ure A M and Bacon J R, 1978 *Comprehensive analysis of soils and rocks by spark-source mass spectrometry*. Analyst, **103**, 807-822.

Ure A M, Bacon J R, Berrow M L and Watt J J, 1979 *The total trace element content of some Scottish soils by spark source mass spectrometry*. Geoderma, 22, 1-23.

Valente I M, Minski M K and Peterson P J 1982 *Neutron activation analysis of noble metals in vegetation*. Journal of Radioanalytical Chemistry, **71**, 115-127.

Vangronsveld J, 1998 *Case studies in the field – arsenic contaminated kitchen gardens*. In Metal-Contaminated Soils: In situ Inactivation and Phytorestoration (ed. J Vangronsveld and S D Cunningham), pp. 227-228. Berlin: Springer-Verlag.

Verstraete D, Riondato J, Vercauteren J, Vanhaecke F, Moens L, Dams R and Verloo M, 1998 *Determination of the uptake of [Pt(NH3)(4)](NO3)(2) by grass cultivated on a sandy loam soil and by cucumber plants, grown hydroponically*. Science of the Total Environment, **218**, No. 2-3, 153-160.

Voland B, Metzner I and Bombach G, 1987 *Zur Selenverteilung in Böden der DDR*. In *Arbeitstagung Mengen- und Spuren Elemente* (ed. M Anke), pp. 1-10. Leipzig: Karl Marx University.

Wedepohl K H, 1969-1974 Editor *Handbook of Geochemistry*. Several volumes. Berlin: Springer Verlag.

Wells N, 1960 *Total elements in topsoils from igneous rocks: an extension of geochemistry*. Journal of Soil Science, **11**, 409-424.

Williams C H and Thornton I, 1972 *The effect of soil additives on the uptake of molybdenum and selenium from soils from different environments*. Plant and Soil, **121**, 395-406.

Xu G I and Jiang Y F, 1985 *Selenium and the prevalence of Keshan and Kashin-Beck disease in China*. In Proceedings of the First International Symposium on Geochemistry and Health (London, 1985), edited by I Thornton, 192.

Yoshida S and Muramatsu, 1997 *Determination of major and trace elements in mushroom, plant and soil samples collected from Japanese forests*. International Journal of Environmental Analytical Chemistry, **67**, 49-58.

Yoshida S, Muramatsu Y, Tagami K and Uchida S, 1998 *Concentrations of lanthanide elements, Th and U in 77 Japanese surface soils*. Environment International, **24**, 275-286.

Zhu J, Zhong G, Kennedy M, de Leer EWB, Bosman R, Kong L and Alaerta GJFR, 1997 *The distribution of rare earth elements (REEs) in Chinese soil*. In Proceedings of the Fourth International Conference of the Biogeochemistry of Trace Elements (Berkeley, CA, 1997), 301.

Appendices 1, 2, 4, 5, 6 and 7 available as an Excel spreadsheet on the CD that accompanies Report No. 1

The CD-ROM is available from the Environment Agency publications catalogue (publications.environment-agency.gov.uk) under the following product code:
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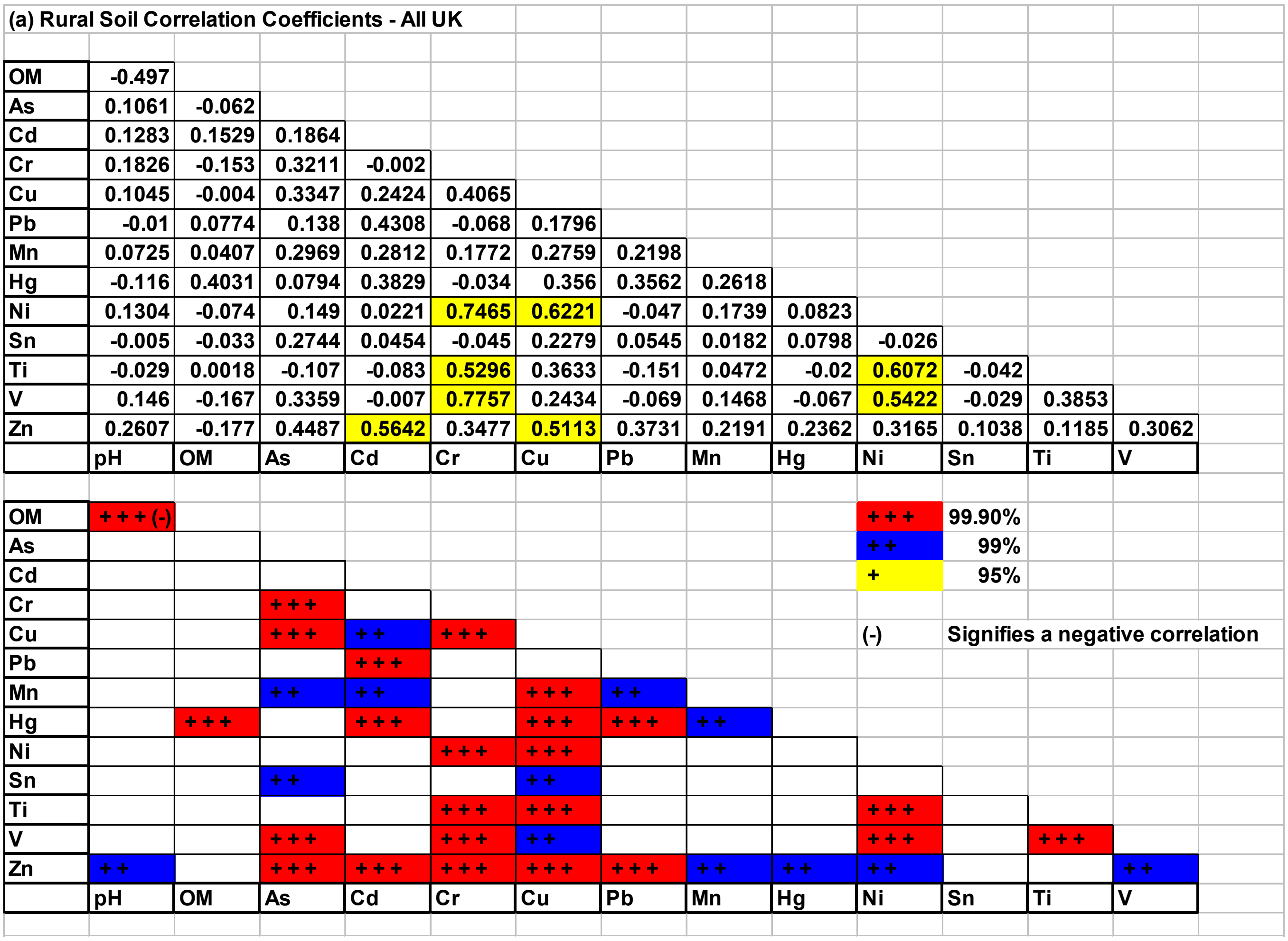
Appendix 3 – Correlation coefficients for soil properties and 12 trace metals/metalloids

(a) All UK data, (b) England, (c) Northern Ireland, (d) Scotland and (e) Wales



(a) Rural Soil Correlation Coefficients - All UK

OM	-0.497												
As	0.1061	-0.062											
Cd	0.1283	0.1529	0.1864										
Cr	0.1826	-0.153	0.3211	-0.002									
Cu	0.1045	-0.004	0.3347	0.2424	0.4065								
Pb	-0.01	0.0774	0.138	0.4308	-0.068	0.1796							
Mn	0.0725	0.0407	0.2969	0.2812	0.1772	0.2759	0.2198						
Hg	-0.116	0.4031	0.0794	0.3829	-0.034	0.356	0.3562	0.2618					
Ni	0.1304	-0.074	0.149	0.0221	0.7465	0.6221	-0.047	0.1739	0.0823				
Sn	-0.005	-0.033	0.2744	0.0454	-0.045	0.2279	0.0545	0.0182	0.0798	-0.026			
Ti	-0.029	0.0018	-0.107	-0.083	0.5296	0.3633	-0.151	0.0472	-0.02	0.6072	-0.042		
V	0.146	-0.167	0.3359	-0.007	0.7757	0.2434	-0.069	0.1468	-0.067	0.5422	-0.029	0.3853	
Zn	0.2607	-0.177	0.4487	0.5642	0.3477	0.5113	0.3731	0.2191	0.2362	0.3165	0.1038	0.1185	0.3062
	pH	**OM**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Mn**	**Hg**	**Ni**	**Sn**	**Ti**	**V**

OM	+ + + (-)												
As													
Cd													
Cr			+ + +										
Cu			+ + +	+ +	+ + +								
Pb				+ + +									
Mn			+ +	+ +		+ + +	+ +						
Hg		+ + +		+ + +		+ + +	+ + +	+ +					
Ni					+ + +	+ + +							
Sn			+ +			+ +							
Ti					+ + +	+ + +				+ + +			
V			+ + +		+ + +	+ +				+ + +		+ + +	
Zn	+ +		+ + +	+ + +	+ + +	+ + +	+ + +	+ +	+ +	+ +			+ +
	pH	**OM**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Mn**	**Hg**	**Ni**	**Sn**	**Ti**	**V**

+ + +	**99.90%**
+ +	**99%**
+	**95%**

(-) **Signifies a negative correlation**

(b) Rural Soil Correlation Coefficients - England

OM	-0.253													
As	0.0662	0.249												
Cd	0.2212	0.1144	0.1464											
Cr	0.0946	0.4129	0.6064	0.0832										
Cu	0.1661	0.2158	0.4889	0.4802	0.154									
Pb	-0.024	0.0443	0.033	0.4118	-0.018	0.2169								
Mn	0.1286	0.2414	0.369	0.4729	0.5157	0.2817	0.0275							
Hg	0.1381	0.0606	0.0334	0.4204	0.0409	0.4206	0.2865	0.1424						
Ni	0.174	0.3853	0.5708	0.2667	0.8364	0.2991	-0.006	0.6926	0.0756					
Sn	-0.077	0.0654	0.2499	-0.003	-0.044	0.3654	0.0048	-0.064	0.0984	-0.026				
Ti	0.0326	-0.042	0.0967	0.1152	0.2493	0.0224	-0.056	0.1783	-0.037	0.2042	0.0712			
V	0.0512	0.4013	0.6264	0.0563	0.9515	0.1215	-0.048	0.4815	-0.036	0.8034	-0.034	0.4275		
Zn	0.1068	0.2858	0.517	0.6536	0.378	0.6764	0.3902	0.4506	0.3123	0.4856	0.0788	0.4143	0.4314	
	pH	**OM**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Mn**	**Hg**	**Ni**	**Sn**	**Ti**	**V**	**Zn**

Rural Soil Correlation Coefficients - England

OM	+ + (-)												
As		+ +											
Cd	+												
Cr		+ + +	+ + +										
Cu		+	+ + +	+ + +									
Pb				+ + +		+ +							
Mn		+ +	+ + +	+ + +	+ + +	+ +							
Hg				+ + +		+ + +	+ +						
Ni		+ + +	+ + +	+ +	+ + +	+ +		+ + +					
Sn			+			+ + +							
Ti					+					+			
V		+ + +	+ + +		+ + +			+ + +		+ + +		+ + +	
Zn		+ +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ +	+ + +		+ + +	+ + +
	pH	**OM**	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Mn**	**Hg**	**Ni**	**Sn**	**Ti**	**V**

+ + +	99.90%
+ +	99%
+	95%

(-) **Signifies a negative correlation**

(c) Rural Soil Correlation Coefficients - Northern Ireland

OM	-0.086												
As	0.0028	-0.291											
Cd	0.327	0.6103	0.0897										
Cr	0.4406	-0.074	-0.124	-0.065									
Cu	0.293	-0.536	0.2121	-0.293	0.5813								
Pb	0.5238	0.006	0.4871	0.3657	0.2438	0.3273							
Mn	0.2117	-0.09	0.6453	0.1449	0.5383	0.4625	0.4779						
Hg	-0.037	0.8226	-0.056	0.4587	-0.031	-0.294	0.4153	0.0796					
Ni	0.3589	-0.142	-0.039	-0.111	0.8804	0.8056	0.3257	0.5237	0.0087				
Sn	0.3271	-0.086	0.4147	0.0974	0.0965	0.3794	-0.11	0.2923	0.3739	0.2683			
Ti	0.038	-0.152	-0.19	-0.372	0.7406	0.7219	0.8881	0.3358	-0.138	0.8724	-0.056		
V	0.3907	-0.067	-0.141	-0.141	0.9705	0.5887	0.1762	0.5602	-0.032	0.8674	0.0635	0.7861	
Zn	0.6872	-0.136	0.3774	0.5471	0.3868	0.5112	0.7129	0.5189	-0.003	0.4838	0.4775	0.1036	0.3076
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

OM													
As													
Cd		+ + +											
Cr	+												
Cu		+ + + (-)			+ + +								
Pb	+ + +		+ +	+									
Mn			+ + +		+ + +	+ +	+ +						
Hg		+ + +		+ +			+						
Ni	+				+ + +	+ + +		+ + +					
Sn			+			+			+				
Ti				+ (-)	+ + +	+ + +	+ + +			+ + +			
V	+				+ + +	+ + +		+ + +		+ + +		+ + +	
Zn	+ + +		+	+ + +	+	+ + +	+ + +	+ + +		+ +	+ +		
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

+ + +	99.90%
+ +	99%
+	95%

(-) Signifies a negative correlation

(d) Rural Soil Correlation Coefficients - Scotland

OM	-0.707												
As	0.0646	-0.01											
Cd	-0.238	0.3963	0.2688										
Cr	0.2958	-0.397	0.0183	-0.15									
Cu	0.07	0.0274	0.1468	0.0339	0.6473								
Pb	-0.272	0.425	0.5845	0.5078	-0.238	0.155							
Mn	0.0441	0.0522	0.6979	0.2308	0.0533	0.3519	0.6082						
Hg	0.4651	0.6434	0.4641	0.5123	-0.096	0.3657	0.7142	0.4881					
Ni	0.1596	-0.134	-0.048	-0.103	0.8376	0.8317	-0.135	0.0687	0.1275				
Sn	-0.206	0.3411	0.6378	0.535	-0.168	0.1637	0.8331	0.6168	0.6637	-0.093			
Ti	0.2165	-0.247	-0.173	-0.09	0.6833	0.5598	-0.216	0.0197	-0.092	0.6994	-0.106		
V	0.2026	-0.297	0.1639	-0.074	0.5665	0.2739	-0.142	0.0289	-0.062	0.4287	-0.097	0.2921	
Zn	0.1483	-0.178	0.1433	0.4058	0.4892	0.5318	0.1377	0.1467	0.1366	0.4102	0.1455	0.4277	0.2696
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

OM	+ + + (-)												
As													
Cd	+ (-)	+ + +	+ +										
Cr	+ +	+ + + (-)											
Cu					+ + +								
Pb	+ + (-)	+ + +	+ + +	+ + +	+ (-)								
Mn			+ + +	+		+ + +	+ + +						
Hg	+ + +	+ + +	+ + +	+ + +		+ + +	+ + +	+ + +					
Ni					+ + +	+ + +							
Sn	+	+ + +	+ + +	+ + +			+ + +	+ + +	+ + +				
Ti	+	+ (-)			+ + +	+ + +	+ (-)			+ + +			
V	+	+ + (-)			+ + +	+ +				+ + +		+ +	
Zn				+ + +	+ + +	+ + +				+ + +		+ + +	+ +
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

+ + +	99.90%
+ +	99%
+	95%

(-) Signifies a negative correlation

(e) Rural Soil Correlation Coefficients - Wales

OM	-0.678												
As	-0.198	0.1632											
Cd	0.1361	-0.157	0.388										
Cr	0.5969	-0.618	-0.07	0.387									
Cu	0.0175	0.1257	0.7047	0.3511	0.014								
Pb	-0.144	0.4142	0.5163	0.4782	-0.109	0.689							
Mn	0.582	0.5455	0.0123	0.7533	0.7308	0.0854	0.1609						
Hg	-0.021	0.3638	0.2677	0.1654	-0.208	0.5671	-0.044	-0.044					
Ni	0.6068	-0.557	-0.074	0.5199	0.8713	0.0813	0.169	0.8039	0.0732				
Sn	0.1348	-0.053	0.2745	0.1895	-0.05	0.2464	0.1247	0.0657	0.0436	-0.044			
Ti	0.2282	-0.2	-0.384	-0.288	-0.079	-0.268	-0.477	-0.073	-0.227	-0.201	-0.176		
V	0.5889	-0.662	-0.236	0.1714	0.9012	-0.154	0.3293	0.5859	-0.329	0.6872	-0.096	0.2203	
Zn	0.5655	-0.338	0.0131	0.4371	0.4774	0.2572	0.456	0.6076	0.5486	0.7426	0.0389	-0.132	0.3424
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

OM	+ + + (-)												
As													
Cd			+										
Cr	+ + +	+ + + (-)		+									
Cu			+ + +	+									
Pb		+	+ + +	+ +		+ + +							
Mn	+ + +	+ + +		+ + +	+ + +								
Hg		+				+ + +							
Ni	+ + +	+ + + (-)		+ + +	+ + +			+ + +					
Sn													
Ti			+ (-)										
V	+ + +	+ + + (-)			+ + +		+	+ + +	+ (-)	+ + +			
Zn	+ + +	+ (-)		+ +	+ +		+ +	+ + +	+ + +	+ + +			+
	pH	OM	As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Sn	Ti	V

+ + +	99.90%
+ +	99%
+	95%

(-) Signifies a negative correlation

Appendix 8 – Concentration factors for all 13 metals/metalloids at rural, urban and industrial sites

(a) Concentration factor – rural sites

Arsenic	*n*	Range	Mean	Median	Standard deviation
UK	364	0.004–1.00	0.121	0.078	0.152
England	183	0.004–0.64	0.08	0.07	0.065
N. Ireland	30	0.03–0.24	0.14	0.14	0.057
Scotland	119	0.008–1.00	0.21	0.09	0.225
Wales	32	0.01–0.16	0.06	0.05	0.036

Cadmium	*n*	Range	Mean	Median	Standard deviation
UK	364	0.056–9.6	0.502	0.392	0.623
England	183	0.06–9.6	0.51	0.38	0.826
N. Ireland	30	0.15–1.38	0.42	0.36	0.266
Scotland	119	0.12–2.24	0.53	0.46	0.333
Wales	32	0.14–1.13	0.40	0.36	0.217

Chromium	*n*	Range	Mean	Median	Standard deviation
UK	364	0.005–0.877	0.084	0.045	0.105
England	183	0.01–0.49	0.06	0.04	0.064
N. Ireland	30	0.01–0.79	0.14	0.08	0.156
Scotland	119	0.01–0.88	0.10	0.05	0.131
Wales	32	0.02–0.43	0.08	0.04	0.102

Copper	*n*	Range	Mean	Median	Standard deviation
UK	364	0.051–2.43	0.488	0.405	0.330
England	183	0.09–1.83	0.47	0.41	0.267
N. Ireland	30	0.16–1.02	0.45	0.43	0.202
Scotland	119	0.05–2.43	0.56	0.45	0.440
Wales	32	0.12–1.23	0.36	0.35	0.190

Lead	*n*	Range	Mean	Median	Standard deviation
UK	364	0.002–1.436	0.061	0.037	0.105
England	183	0.002–0.56	0.04	0.03	0.055
N. Ireland	30	0.03–0.85	0.11	0.08	0.147
Scotland	119	0.01–1.44	0.08	0.04	0.145
Wales	32	0.01–0.44	0.05	0.03	0.077

Manganese	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.017–85.9	2.085	0.449	7.106
England	183	0.02–15.81	0.64	0.28	1.411
N. Ireland	30	0.13–4.58	0.98	0.49	1.016
Scotland	119	0.04–85.9	4.79	0.65	11.809
Wales	32	0.05–8.43	1.30	0.47	1.981

Mercury	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.057–1.886	0.698	0.727	0.260
England	183	0.06–1.6	0.76	0.78	0.235
N. Ireland	30	0.26–1.00	0.65	0.65	0.217
Scotland	119	0.15–1.89	0.64	0.62	0.259
Wales	32	0.11–1.12	0.60	0.64	0.242

Nickel	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.627–0.862	0.136	0.093	0.145
England	183	0.02–0.78	0.12	0.08	0.116
N. Ireland	30	0.63–0.32	0.67	0.9	0.195
Scotland	119	0.01–0.86	0.18	0.12	0.158
Wales	32	0.03–0.83	0.13	0.08	0.153

Platinum	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.909–8.6	1.021	1.00	0.397
England	183	0.91–1.00	0.99	1.00	0.007
N. Ireland	30	1.00–1.00	1.00	1.00	0.000
Scotland	119	1.00–8.60	1.06	1.00	0.694
Wales	32	1.00–1.00	1.00	1.00	0.000

Tin	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.017–1.483	0.846	1.00	0.253
England	183	0.02–1.48	0.80	0.96	0.274
N. Ireland	30	0.38–1.22	0.95	1.00	0.166
Scotland	119	0.24–1.28	0.91	1.00	0.200
Wales	32	0.04–1.00	0.75	0.77	0.287

Titanium	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.002–0.852	0.066	0.035	0.095
England	183	0.004–0.85	0.06	0.04	0.099
N. Ireland	30	0.005–0.29	0.08	0.04	0.087
Scotland	119	0.002–0.53	0.05	0.02	0.082
Wales	32	0.01–0.45	0.11	0.09	0.112

Vanadium	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.004–0.917	0.0917	0.056	0.120
England	183	0.01–0.36	0.06	0.05	0.049
N. Ireland	30	0.01–0.33	0.10	0.08	0.083
Scotland	119	0.004–0.92	0.13	0.06	0.184
Wales	32	0.03–0.41	0.09	0.06	0.095

Zinc	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK	364	0.062–15.703	0.726	0.485	1.106
England	183	0.06–3.29	0.49	0.40	0.390
N. Ireland	30	0.21–3.33	0.88	0.62	0.671
Scotland	119	0.19–15.7	1.05	0.57	1.726
Wales	32	0.10–5.51	0.71	0.41	0.946

(b) Concentration factor – urban sites

Arsenic	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.016–0.617	0.133	0.093	0.131
England	42	0.018–0.539	0.114	0.056	0.138
N. Ireland	18	0.049–0.508	0.158	0.126	0.108
Scotland	18	0.055–0.617	0.181	0.141	0.147
Wales	9	0.016–0.163	0.076	0.076	0.056

Cadmium	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.083–1.890	0.559	0.479	0.353
England	42	0.083–1.250	0.50	0.442	0.301
N. Ireland	18	0.147–1.89	0.729	0.697	0.430
Scotland	18	0.318–1.487	0.642	0.531	0.343
Wales	9	0.084–0.976	0.330	0.202	0.279

Chromium	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.008–0.771	0.132	0.077	0.144
England	42	0.020–0.771	0.138	0.062	0.166
N. Ireland	18	0.008–0.468	0.010	0.033	0.143
Scotland	18	0.018–0.469	0.169	0.137	0.114
Wales	9	0.048–0.210	0.100	0.098	0.056

Copper	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.034–1.387	0.401	0.340	0.270
England	42	0.034–1.028	0.357	0.281	0.262
N. Ireland	18	0.104–0.879	0.409	0.357	0.262
Scotland	18	0.153–1.387	0.459	0.413	0.274
Wales	9	0.068–0.946	0.473	0.476	0.323

Lead	*n*	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.005–0.573	0.106	0.053	0.125
England	42	0.005–0.489	0.099	0.038	0.124
N. Ireland	18	0.005–0.410	0.110	0.063	0.127
Scotland	18	0.007–0.573	0.152	0.112	0.145
Wales	9	0.006–0.113	0.037	0.032	0.032

Manganese	*n*	Range	Mean	Median	Standard deviation
UK		0.035–3.587	0.614	0.377	0.687
England	42	0.035–3.587	0.781	0.311	0.906
N. Ireland	18	0.188–0,678	0.406	0.399	0.172
Scotland	18	0.199–1.705	0.620	0.483	0.404
Wales	9	0.044–0.715	0.246	0.119	0.237

Mercury	*n*	Range	Mean	Median	Standard deviation
UK		0.046–1.325	0.426	0.366	0.299
England	42	0.046–1.325	0.314	0.276	0.240
N. Ireland	18	0.074–1.00	0.616	0.547	0.336
Scotland	18	0.135–1.192	0.421	0.340	0.286
Wales	9	0.223–1.031	0.576	0.519	0.277

Nickel	*n*	Range	Mean	Median	Standard deviation
UK		0.020–0.795	0.174	0.133	0.141
England	42	0.027–0.795	0.187	0.137	0.163
N. Ireland	18	0.026–0.359	0.135	0.096	0.111
Scotland	18	0.020–0.492	0.217	0.241	0.130
Wales	9	0.05–0.176	0.110	0.123	0.043

Platinum	*n*	Range	Mean	Median	Standard deviation
UK		1.00	1.00	1.00	0
England	42	1.00	1.00	1.00	0
N. Ireland	18	1.00	1.00	1.00	0
Scotland	18	1.00	1.00	1.00	0
Wales	9	1.00	1.00	1.00	0

Tin	*n*	Range	Mean	Median	Standard deviation
UK		0.036–1.000	0.474	0.370	0.315
England	42	0.036–1.00	0.348	0.288	0.252
N. Ireland	18	0.157–1.00	0.778	0.933	0.320
Scotland	18	0.083–1.00	0.397	0.342	0.228
Wales	9	0.248–1.00	0.607	0.533	0.295

Titanium	*n*	Range	Mean	Median	Standard deviation
UK		0.002–0.688	0.123	0.069	0.131
England	42	0.018–0.689	0.149	0.077	0.161
N. Ireland	18	0.002–0.226	0.052	0.026	0.072
Scotland	18	0.004–0.278	0.144	0.152	0.091
Wales	9	0.044–0.251	0.102	0.061	0.074

Vanadium	*n*	Range	Mean	Median	Standard deviation
UK		0.015–0.634	0.107	0.066	0.105
England	42	0.026–0.634	0.108	0.057	0.122
N. Ireland	18	0.015–0.367	0.083	0.047	0.097
Scotland	18	0.030–0.382	0.129	0.097	0.093
Wales	9	0.069–0.156	0.106	0.098	0.037

Zinc	***n***	**Range**	**Mean**	**Median**	**Standard deviation**
UK		0.076–1.433	0.596	0.571	0.308
England	42	0.094–1.433	0.550	0.469	0.313
N. Ireland	18	0.187–1.074	0.581	0.471	0.307
Scotland	18	0.362–1.306	0.703	0.687	0.234
Wales	9	0.076–1.021	0.621	0.683	0.402

(c) Concentration factors for different types of industries

Incinerator sites

Metal	**Range**	**Mean**	**Median**	**Standard deviation**
Arsenic	0.002–0.268	0.088	0.054	0.076
Cadmium	0.064–3.59	0.659	0.409	0.779
Chromium	0.018–0.424	0.106	0.049	0.103
Copper	0.012–3.352	0.423	0.240	0.640
Lead	0.007–0.370	0.085	0.038	0.101
Manganese	0.042–19.407	1.297	0.238	3.665
Mercury	0.053–1.245	0.438	0.407	0.305
Nickel	0.027–4.098	0.288	0.141	0.707
Platinum	0.445–1.00	0.957	1.00	0.138
Tin	0.042–1.00	0.398	0.311	0.314
Titanium	0.004–0.564	0.098	0.046	0.123
Vanadium	0.011–0.317	0.079	0.052	0.074
Zinc	0.132–3.673	0.657	0.378	0.866

Power station

Metal	**Range**	**Mean**	**Median**	**Standard deviation**
Arsenic	0.018–0.182	0.059	0.043	0.037
Cadmium	0.031–2.326	0.569	0.402	0.482
Chromium	0.012–0.414	0.055	0.035	0.073
Copper	0.054–1.608	0.339	0.250	0.311
Lead	0.005–0.205	0.046	0.032	0.042
Manganese	0.017–3.342	0.504	0.186	0.831
Mercury	0.042–1.486	0.583	0.561	0.348
Nickel	0.020–0.444	0.098	0.069	0.091
Platinum	1.00–1.00	1.00	1.00	0.00
Tin	0.018–1.000	0.640	0.650	0.326
Titanium	0.004–0.238	0.043	0.037	0.044
Vanadium	0.002–0.165	0.054	0.048	0.033
Zinc	0.121–1.219	0.418	0.367	0.275

Mineral

Metal	Range	Mean	Median	Standard deviation
Arsenic	0.0136–30.200	1.499	0.066	0.576
Cadmium	0.018–3.12	0.398	0.258	0.643
Chromium	0.019–30.000	1.477	0.038	6.536
Copper	0.075–3.924	0.518	0.276	0.806
Lead	0.004–27.000	1.328	0.035	5.882
Manganese	0.033–15.084	0.901	0.145	3.255
Mercury	0.112–1.199	0.704	0.778	0.285
Nickel	0.028–14.700	0.768	0.048	3.192
Platinum	1.000–1.000	1.000	1.000	0.000
Tin	0.332–1.00	0.730	0.737	0.251
Titanium	0.021–29.400	1.464	0.055	6.401
Vanadium	0.013–20.55	1.027	0.047	4.473
Zinc	0.019–3.636	0.471	0.247	0.745

Non-ferrous metal

Metal	Range	Mean	Median	Standard deviation
Arsenic	0.007–5.827	0.318	0.061	1.151
Cadmium	0.025–0.950	0.378	0.315	0.269
Chromium	0.014–9.524	0.453	0.047	0.047
Copper	0.019–1.390	0.283	0.178	0.318
Lead	0.007–9.365	0.483	0.033	1.860
Manganese	0.044–4.231	0.564	0.143	0.915
Mercury	0.181–1.729	0.579	0.412	0.434
Nickel	0.037–0.510	0.145	0.103	0.111
Platinum	0.238–1.000	0.885	1.00	0.269
Tin	0.049–1.04	0.449	0.312	0.345
Titanium	0.004–26.419	1.135	0.04	5.269
Vanadium	0.030–6.619	0.335	0.061	1.310
Zinc	0.079–1.552	0.488	0.359	0.409

Steel

Metal	Range	Mean	Median	Standard deviation
Arsenic	0.009–0.340	0.062	0.040	0.065
Cadmium	0.046–4.890	0.527	0.273	0.845
Chromium	0.018–1.015	0.114	0.046	0.193
Copper	0.036–1.222	0.295	0.280	0.223
Lead	0.010–1.129	0.129	0.066	0.205
Manganese	0.021–5.656	0.454	0.199	1.003
Mercury	0.014–1.600	0.590	0.577	0.367
Nickel	0.024–0.448	0.108	0.075	0.107
Platinum	0.541–1.00	0.986	1.00	0.081
Tin	0.011–1.373	0.557	0.560	0.352
Titanium	0.010–0.416	0.090	0.045	0.099
Vanadium	0.013–0.365	0.068	0.040	0.079
Zinc	0.067–3.277	0.435	0.283	0.615

Appendix 9 – Concentrations of 37 elements in UK industrial soils studied semi-quantitatively using ICPMS analysis

(a) Group I: lithium, rubidium, caesium, silver

Industry	Country	Li	Rb	Cs	Ag
Chemical	England	9.3–17.9	18.4–29.6	1.5–2.2	1.0–133.0
	Scotland	10.4–22.4	8.7–32.5	0.6–1.5	ND–0.1
	Wales	18.0–47.9	19.9–44.0	2.2–4.9	ND–0.3
General	N. Ireland	4.4–29.4	4.6–27.9	0.3–1.4	0.1–0.3
Incinerator sites	England	1.0–37.9	4.9–57.9	0.6–4.1	0.1–1.7
	Scotland	16.1–33.2	12.9–32.1	1.1–1.7	0.1–0.2
	Wales	17.6–28.0	16.0–36.4	1.7–3.0	0.2–0.4
Landfill sites	England	16.2–24.4	17.0–23.6	2.0–2.9	ND
	Wales	25.9–42.3	23.1–31.2	2.71–4.98	ND–0.061
Mineral	England	13.0–33.3	17.7–35.1	1.2–3.2	ND–0.1
	N. Ireland	5.7–18.9	8.6–25.6	0.7–1.7	ND–0.023
	Scotland	3.8–229.0	3.4–31.6	0.3–2.7	0.1
	Wales	22.9–29.4	20.1–34.9	2.5–5.0	0.1–1.0
Non-ferrous metals	England	9.7–41.8	7.8–47.3	0.7–4.7	ND–2.1
	Scotland	5.5–19.4	8.8–33.2	0.7–2.3	ND–0.1
	Wales	8.7–29.0	12.2–28.6	0.6–2.3	ND–0.6
Oil refinery	Scotland	0.104–37.6	0.603–37.2	0.053–2.9	0.054–0.2
	Wales	20.4–33.8	20.3–34.8	1.7–2.5	ND–0.1
Paper	England	8.8–17.4	21.9–43.2	1.2–2.4	0.1–0.3
Power station	England	5.5–71.3	12.6–59.9	0.7–36.9	ND–0.8
	N. Ireland	15.7–27.0	18.4–37.7	1.3	ND–0.1
	Scotland	8.5–23.6	10.1–28.6	0.5–2.2	0.1–0.2
	Wales	24.7–35.3	20.0–44.5	1.8–3.7	0.1
Steel	England	9.7–45.0	6.4–38.7	0.9–3.8	ND–1.8
	Scotland	21.9–23.3	25.2–27.7	1.73–1.94	0.355–0.468
	Wales	10.5–47.8	8.5–78.4	0.9–5.9	ND–0.5
Tar/bitumen	England	8.8–18.7	9.5–21.0	0.9–1.5	0.1–0.2
Textile	N. Ireland	3.2–25.9	6.7–24.1	0.3–0.3	ND–0.1

Location	Country	Li	Rb	Ce	Ag
Rural	England	20.9–26.9	28.1–40.4	1.6–4.1	ND
	Scotland	13.7	13.4	1.01	0.225
	Wales	15.6	7.0	1.9	0.3
Urban	Scotland	18.7	19.6	1.4	0.1

(b) Group II: beryllium, strontium, barium

Industry	Country	Be	Sr	Ba
Chemical	England	0.5–1.1	30.5–134.0	128.0–296.0
	Scotland	0.6–1.1	33.0–64.0	72.9–641.0
	Wales	0.6–1.6	27.0–147.0	68.0–339.0
General	N. Ireland	0.4–0.9	19.8–26.0	93.3–176.0
Incinerator sites	England	ND–2.0	4.2–94.6	11.4–216.0
	Scotland	0.8–2.4	17.8–58.5	12.6–272.0
	Wales	0.5–1.3	14.4–108.0	89.4–504.0
Landfill sites	England	0.5–1.2	13.2–102.0	63.9–125.0
	Wales	0.7–0.965	9.88–50.5	97.6–145.0
Mineral	England	0.6–2.5	15.1–363.0	66.6–553.0
	N. Ireland	0.2–0.6	18.6–55.0	27.2–113.0
	Scotland	0.1–1.2	15.7–118.0	23.2–227.0
	Wales	0.6–0.9	11.2–23.9	90.7–148.0
Non-ferrous metals	England	0.4–2.0	12.7–48.9	23.1–313.0
	Scotland	0.3–0.9	16.0–24.5	24.9–75.5
	Wales	0.4–0.744	12.9–136.0	34.6–188.0
Oil refinery	Scotland	0.04–1.4	25.7–106.0	13.3–109.0
	Wales	0.6–1.0	9.5–34.4	59.2–83.4
Paper	England	0.7–1.4	15.0–39.3	78.1–148.0
Power station	England	0.4–2.5	5.6–138.0	22.8–1210.0
	N. Ireland	0.5–0.9	69.8–125.0	69.0–118.0
	Scotland	0.7–1.9	36.7–83.9	104.0–316.0
	Wales	0.9–1.5	23.7–203.0	86.9–216.0
Steel	England	0.6–2.5	ND–221.0	37.4–684.0
	Scotland	2.06–2.88	41.5–85.8	249.0–256.0
	Wales	0.3–8.2	10.6–281.0	54.0–429.3
Tar/bitumen	England	1.1–2.5	19.1–154.0	75.4–152.0
Textile	N. Ireland	0.1–0.6	8.5–28.9	21.9–57.7

Location	Country	Be	Sr	Ba
Rural	England	0.5–0.6	8.6–8.7	81.2–281.0
	Scotland	0.302	9.12	117.0
	Wales	0.4	4.9	29.4
Urban	Scotland	1.0	13	95.1

(c) Group III: boron, gallium, thallium, scandium, yttrium

Industry	Country	B	Ga	Tl	Sc	Y
Chemical	England	12.0–33.3	3.3–6.1	0.2–0.3	1.6–3.7	5.0–12.6
	Scotland	7.8–11.2	4.8–12.7	0.2	0.6–1.9	4.3–8.8
	Wales	4.5–15.9	3.1–7.9	0.1–0.5	0.9–2.2	5.8–11.6
General	N. Ireland	6.0–32.7	1.7–7.5	0.1–0.3	0.4–1.1	3.5–7.2
Incinerator sites	England	7.6–31.7	1.2–11.6	ND–0.8	0.7–4.5	1.1–16.1
	Scotland	6.0–24.3	6.6–11.5	0.1–0.4	0.6–3.5	6.2–10.9
	Wales	3.7–22.5	5.1–8.4	0.2–0.4	0.5–4.2	4.3–11.6
Landfill sites	England	12.7–26.1	4.0–6.1	0.1–0.2	2.0–3.8	5.0–11.0
	Wales	14.4–22.3	5.0–6.65	0.1–0.2	0.106–1.9	5.47–13.4
Mineral	England	5.6–21.8	3.5–8.6	0.2–0.4	0.3–4.6	7.0–37.9
	N. Ireland	5.1–11.3	2.6–5.7	0.1–0.2	ND–0.7	2.3–8.2
	Scotland	9.0–13.9	0.8–8.85	ND–0.3	0.3–2.01	2.0–8.2
	Wales	11.1–12.9	4.4–7.3	0.3–0.7	0.4–0.6	3.7–5.5
Non-ferrous metals	England	4.0–23.0	1.8–7.8	0.1–0.7	0.047–1.0	2.3–15.7
	Scotland	2.4–28.3	5.8–25.8	0.1–0.3	1.3–1.5	5.7–13.6
	Wales	6.5–19.3	4.3–8.26	0.073–0.3	ND–2.6	3.1–11.1
Oil refinery	Scotland	6.5–27.5	0.311–84.2	0.014–0.2	ND–3.7	0.28–12.0
	Wales	7.1–15.9	6.4–9.0	0.1–0.2	0.8–3.1	4.8–11.3
Paper	England	10.9–15.2	3.4–6.1	0.2–0.3	1.6–3.0	7.0–10.8
Power station	England	7.1–40.6	1.9–11.3	0.094–0.7	0.1–6.5	2.1–16.3
	N. Ireland	9.8–26.5	5.9–7.3	0.1–0.2	0.8–3.0	8.2–22.8
	Scotland	6.6–17.4	3.4–6.5	0.1–0.2	0.3–1.2	5.1–10.9
	Wales	13.7–25.4	5.8–7.9	0.3–0.5	0.6–2.0	7.3–50.0
Steel	England	8.0–57.5	2.5–8.7	0.1–0.6	0.9–4.0	4.8–17.7
	Scotland	16.0–21.8	11.9	0.351–0.399	1.45–1.46	11.4–13.2
	Wales	1.0–29.2	5.1–44.9	0.2–1.0	0.1–2.8	2.7–22.6
Tar/ bitumen	England	10.1–17.9	3.3–49.9	0.1–0.2	0.9–2.8	12.5–24.9
Textile	N. Ireland	8.6–12.1	1.9–5.5	ND–0.2	0.2–1.4	2.3–10.5

Location	Country	B	Ga	Tl	Sc	Y
Rural	England	11.9–34.4	5.5–5.6	0.2	1.3–1.7	3.9–5.1
	Scotland	7.11	6.84	0.431	0.07	6.11
	Wales	2.0	4.9	0.2	0.3	6.2
Urban	Scotland	34.1	5.8	0.2	1.4	6.8

(d) Lanthanides: Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium

Industry	Country	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Chemical	England	17.4–34.9	16.9–33.8	2.4–5.0	8.6–16.6	1.4–3.0	0.3–0.7	1.2–2.7	0.2–0.4	0.8–2.1	0.1–0.3	0.4–1.0	ND–0.1	0.4–1.0	ND–0.1
	Scotland	14.7–20.8	20.2–38.0	3.1–4.4	10.6–14.3	1.7–2.4	0.3–0.7	1.4–2.1	0.2–0.3	0.8–1.6	0.1–0.2	0.3–0.6	ND–0.1	0.3–0.6	ND–0.1
	Wales	21.6–43.7	21.0–376	3.0–5.5	10.2–18.4	1.8–3.3	0.4–0.7	1.7–3.1	0.2–0.3	1.0–1.9	0.2–0.3	0.4–0.8	ND–0.1	0.4–0.8	ND–0.1
General	N. Ireland	10.4–24.9	10.2–24.1	1.5–3.5	5.0–11.9	0.8–2.1	0.2–0.5	0.7–1.8	0.1–0.2	0.5–1.3	0.1–0.2	0.2–0.5	ND–0.1	0.3–0.5	ND–0.1
Incinerator sites	England	11.5–45.2	4.6–40.0	1.7–5.9	5.4–50.0	0.8–3.4	0.1–0.8	0.6–3.0	ND–0.4	0.3–2.2	ND–0.4	ND–1.0	ND–0.2	ND–1.1	ND–0.1
	Scotland	31.3–38.2	28.6–37.7	3.2–5.9	10.2–18.8	1.7–2.9	0.4–0.8	1.5–2.6	0.2–0.3	1.0–1.8	0.2–0.3	0.5–0.8	ND–0.1	0.5–0.8	ND–0.1
	Wales	17.7–43.2	17.1–387	2.3–5.5	7.3–18.8	1.3–3.3	0.3–0.7	1.2–2.7	0.1–0.3	0.8–1.3	0.1–0.3	0.3–0.8	ND–0.1	0.3–0.7	ND–0.1
Landfill sites	England	21.6–31.0	20.8–29.9	3.2–4.9	10.6–14.2	1.8–3.4	0.3–0.7	1.5–3.0	0.2–0.4	1.0–2.0	0.1–0.3	0.4–0.9	ND–0.1	0.3–0.6	ND–0.1
	Wales	22.9–40.5	19.0–30.7	2.67–4.54	9.15–15.3	1.55–3.01	0.32–0.63	1.27–2.49	0.149–0.3	0.781–1.6	0.122–0.3	0.338–0.8	ND–0.109	0.333–0.8	ND–0.043
Mineral	England	20.9–91.9	ND–47.6	1.5–6.6	ND–22.0	ND–3.8	ND–0.8	1.7–6.4	0.2–0.8	1.2–4.8	0.2–0.8	0.6–2.3	ND–0.3	0.5–2.4	ND–0.7
	N. Ireland	9.5–23.0	9.3–22.9	1.2–3.4	4.0–10.9	0.6–1.8	0.1–0.4	0.5–1.6	0.1–0.2	0.4–1.1	0.1–0.2	0.2–0.5	ND–0.1	0.2–4.5	ND–0.1
	Scotland	6.9–54.4	6.9–41.2	1.0–5.6	3.4–17.1	0.6–5.9	0.1–0.544	0.5–2.0	ND–0.2	0.3–1.4	ND–0.2	0.2–0.6	ND–0.1	0.2–1.6	ND–0.1
	Wales	18.1–21.6	14.8–20.7	2.1–3.1	7.1–10.4	1.2–1.9	0.3–0.4	1.1–1.6	0.1–0.2	0.6–0.9	0.1	0.2–0.4	ND	0.2–0.3	ND
Non-ferrous metals	England	11.8–38.9	11.3–34.7	1.7–5.1	5.4–17.2	0.9–3.2	0.2–0.7	0.7–2.8	0.1–0.3	0.9–1.9	0.1–0.3	0.2–0.9	ND–0.1	0.2–0.9	ND–0.1
	Scotland	23.3–59.3	22.4–52.7	3.1–7.1	9.9–22.6	1.6–3.8	0.3–0.7	1.3–3.2	0.2–0.4	1.0–2.3	0.2–0.4	0.5–1.1	ND–0.2	0.5–1.2	ND–0.2
	Wales	12.5–52.5	12.1–43.1	0.7–6.28	1.8–20.9	1.1–3.52	0.2–0.79	0.9–2.7	0.1–0.7	0.6–1.51	ND–0.241	0.2–0.652	ND–0.092	0.2–0.625	ND–0.076
Oil refinery	Scotland	0.82–57.8	0.82–53.6	0.116–7.9	0.38–26.2	0.064–2.8	0.015–0.9	0.05–3.5	0.006–0.4	0.036–2.3	0.006–0.3	0.015–0.9	0.002–0.1	0.017–0.9	0.002–0.1
	Wales	26.8–51.3	24.5–49.8	2.9–5.3	9.4–21.5	1.6–3.2	0.3–0.6	1.4–2.7	0.2–0.3	0.9–1.8	0.1–0.6	0.4–0.8	ND–0.1	0.4–0.8	ND–0.1
Paper	England	35.9–43.1	33.0–39.3	4.7–5.5	15.1–18.0	2.4–3.2	0.4–0.6	1.9–2.6	0.2–0.3	1.1–1.6	0.2–0.3	0.5–0.7	0.1	0.4–0.7	0.1

Industry	Country	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Power station	England	8.3–49.8	8.0–43.7	1.2–6.4	4.1–21.5	0.7–3.8	0.2–0.8	0.871–3.4	0.098–0.4	0.4–2.6	0.064–0.4	0.2–1.3	ND–0.2	0.2–1.5	ND–0.2
	N. Ireland	18.0–35.4	18.4–28.0	2.8–5.9	9.4–20.7	1.7–3.4	0.4–0.8	1.6–3.4	0.2–0.4	1.2–2.5	0.2–0.4	0.6–1.2	0.1–0.2	0.6–1.1	ND–0.1
	Scotland	21.8–51.7	21.8–46.8	3.1–6.6	10.2–21.5	1.6–3.5	0.4–0.7	1.4–2.9	0.2–0.3	0.9–1.8	0.1–0.3	0.4–0.8	ND–1.1	0.3–0.8	ND–0.1
	Wales	18.5–47.1	ND–40.7	0.1–6.2	ND–21.5	0.8–3.8	0.1–0.9	1.6–5.5	0.2–0.7	1.2–4.5	0.2–0.8	0.5–2.4	0.1–0.3	0.6–2.5	0.2–0.3
Steel	England	16.3–44.0	15.7–33.0	2.4–5.6	8.0–19.2	1.4–3.9	0.3–0.9	1.2–3.9	0.1–0.5	0.8–3.1	0.1–0.5	0.4–1.6	0.1–0.3	0.4–1.9	0.1–2.5
	Scotland	55.2–56.6	37.3–45.4	5.47–6.55	17.8–20.7	2.88–3.41	0.66–0.79	2.58–2.74	0.33–0.33	1.63–1.8	0.26–0.3	0.69–0.81	0.1–0.12	0.69–0.82	0.09–0.13
	Wales	18.9–57.8	16.8–54.6	2.4–8.1	7.5–27.2	1.4–4.5	0.4–1.1	1.4–4.7	0.1–0.6	0.7–3.2	ND–0.5	0.2–1.5	ND–0.2	0.2–1.5	ND–0.2
Tar/ bitumen	England	31.1–54.8	28.1–51.2	3.8–6.8	13.1–23.6	3.1–26.0	0.6–1.2	2.5–4.9	0.3–0.7	2.1–4.2	0.3–0.7	1.0–2.2	0.2–0.3	1.2–2.5	0.1–0.3
Textile	N. Ireland	11.1–49.5	11.4–40.3	1.6–5.7	4.9–18.4	0.8–2.9	0.2–0.7	0.6–2.8	ND–0.3	0.4–1.8	ND–0.3	0.2–0.8	ND–0.1	0.2–0.8	ND–0.1

Location	Country	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Rural	England	20.6–25.1	20.0–24.1	3.0–3.7	9.6–12.4	1.6–2.1	0.3–0.4	1.2–1.7	0.1–0.2	0.7–1.0	0.1–0.2	0.3–0.4	ND	0.3–0.4	ND
	Scotland	64.2	21.4	2.54	8.02	1.16	0.315	1.98	0.221	1.04	0.145	0.353	0.046	0.289	0.033
	Wales	22.8	48.0	6.2	20.3	3.4	0.7	2.7	0.3	1.6	0.2	0.6	ND	0.5	ND
Urban	Scotland	32.5	31.0	4.6	15.0	2.3	0.5	1.9	0.2	1.3	0.2	0.5	0.1	0.5	0.1

(e) Actinides: thorium, uranium

Industry	Country	Th	U
Chemical	England	0.4–1.7	0.6–0.8
	Scotland	0.4–0.6	0.7–1.4
	Wales	0.6–3.2	0.6–1.0
General	N. Ireland	0.1–0.3	0.4–1.4
Incinerator sites	England	0.3–3.5	0.2–1.4
	Scotland	0.5–2.6	0.9–2.5
	Wales	0.2–2.5	0.9–1.3
Landfill sites	England	2.1–4.5	0.9–1.1
	Wales	0.326–2.62	0.729–0.8
Mineral	England	0.3–6.4	0.7–1.5
	N. Ireland	ND–0.7	0.6–1.7
	Scotland	0.2–2.16	0.3–1.1
	Wales	0.4–2.1	0.7–1.2
Non–ferrous metals	England	0.1–2.8	0.4–1.2
	Scotland	0.9–6.5	0.8–3.3
	Wales	ND–1.3	0.6–1.8
Oil refinery	Scotland	0.089–6.6	0.152–2.3
	Wales	ND–2.4	0.8–1.3
Paper	England	1.0–3.3	0.7–1.0
Power station	England	0.2–6.8	0.3–2.2
	N. Ireland	0.2–1.5	0.7–2.0
	Scotland	0.2–6.3	0.5–1.4
	Wales	0.6–4.7	0.7–1.1
Steel	England	1.2–5.4	0.7–1.7
	Scotland	1.28–1.49	1.38–1.48
	Wales	0.5–4.8	0.5–7.8
Tar/bitumen	England	3.7–14.5	0.7–1.3
Textile	N. Ireland	ND–2.8	0.6–1.2

Location	Country	Th	U
Rural	England	0.2–0.5	0.4–0.9
	Scotland	0.06	0.653
	Wales	ND	0.8
Urban	Scotland	1.6	2.0

(f) Group IV: germanium, zirconium

Industry	Country	Ge	Zr
Chemical	England	0.1–0.3	ND–0.7
	Scotland	ND–0.3	ND–0.5
	Wales	ND–0.1	0.1–0.8
General	N. Ireland	ND–0.2	ND–0.1
Incinerator sites	England	ND–0.1	ND–1.3
	Scotland	ND–0.2	ND–1.1
	Wales	ND–0.4	ND–0.7
Landfill sites	England	ND	0.2–1.0
	Wales	ND–0.103	0.087–0.721
Mineral	England	ND–0.3	ND–0.9
	N. Ireland	ND	ND–0.2
	Scotland	ND–0.119	ND–0.439
	Wales	0.1	0.1–0.3
Non–ferrous metals	England	ND–0.2	ND–0.6
	Scotland	0.1	0.5–1.5
	Wales	ND–0.115	ND–0.5
Oil refinery	Scotland	0.045–0.3	0.2–1.32
	Wales	ND	0.1–0.7
Paper	England	0.1–0.2	0.1–1.9
Power station	England	ND–0.3	ND–1.3
	N. Ireland	ND–0.3	0.1–0.2
	Scotland	ND–0.4	ND–1.2
	Wales	ND–0.1	0.3–1.5
Steel	England	0.1–0.7	ND–5.4
	Scotland	0.274–0.599	0.167–0.197
	Wales	ND–0.5	0.2–6.0
Tar/bitumen	England	0.2–0.4	0.1–8.5
Textile	N. Ireland	ND	ND–0.4

Location	Country	Ge	Zr
Rural	England	ND	ND–0.2
	Scotland	0.088	0.038
	Wales	ND	ND
Urban	Scotland	0.1	0.2

(g) Group V: antimony, bismuth, niobium

Industry	**Country**	**Sb**	**Bi**	**Nb**
Chemical	England	3.0–17.0	0.3–11.4	0.5–0.8
	Scotland	0.2–0.6	ND–0.1	0.4–16.7
	Wales	0.5–3.4	0.2–0.6	0.3–0.7
General	N. Ireland	0.8–1.6	0.1–0.2	0.2–0.4
Incinerator sites	England	0.4–6.1	ND–0.9	0.2–1.4
	Scotland	0.5–1.7	0.1–2.0	0.4–2.4
	Wales	1.3–38.4	0.4–2.0	0.3–0.6
Landfill sites	England	0.4–0.6	ND–0.1	0.2–0.3
	Wales	0.54–0.957	0.1–0.2	0.4–0.513
Mineral	England	0.5–1.5	0.2–0.6	0.4–1.1
	N. Ireland	0.3–0.4	0.1	0.1–0.6
	Scotland	0.2–4.0	ND–0.3	0.3–1.5
	Wales	0.6–0.9	0.2–0.4	0.3–0.4
Non-ferrous metals	England	0.3–17.0	0.1–1.1	0.2–0.7
	Scotland	0.2–0.4	0.2–0.4	1.3–1.9
	Wales	0.5–6.0	0.3–1.9	0.2–0.929
Oil refinery	Scotland	0.403–1.3	0.043–0.3	0.082–1.4
	Wales	0.4–0.5	0.2–0.3	0.3–0.7
Paper	England	1.2–1.5	0.1–1.0	0.6
Power station	England	0.5–5.2	0.1–1.2	0.2–1.2
	N. Ireland	0.3–1.7	0.1–0.2	0.5–0.7
	Scotland	0.3–0.7	ND–0.2	0.4–1.1
	Wales	0.3–1.4	0.2–0.4	0.2–0.5
Steel	England	0.5–21.8	0.1–1.5	0.2–2.5
	Scotland	1.75–2.27	0.336–0.377	0.997–1.08
	Wales	0.5–7.2	0.2–1.7	0.2–5.2
Tar/bitumen	England	0.8–2.4	0.5–0.6	0.6–1.4
Textile	N. Ireland	0.2–0.4	ND–0.2	0.3–0.9

Location	**Country**	**Sb**	**Bi**	**Nb**
Rural	England	0.6–0.7	0.2	0.4–0.5
	Scotland	1.55	0.471	0.478
	Wales	1.0	1.4	0.2
Urban	Scotland	0.6	0.2	1.1

(h) Group VI: selenium, molybdenum, tungsten

Industry	Country	Se	Mo	W
Chemical	England	2.1–52.4	1.4–2.8	0.3–0.9
	Scotland	ND–1.0	0.5–1.2	ND–0.2
	Wales	1.2–2.5	0.6–2.6	0.1–0.4
General	N. Ireland	ND–2.5	1.2–2.1	0.1–0.3
Incinerator sites	England	ND–2.6	0.7–7.5	ND–2.6
	Scotland	ND–1.2	0.5–1.4	ND–0.3
	Wales	ND–10.9	1.2–22.2	0.2–5.7
Landfill sites	England	ND–1.1	ND–0.9	ND–0.1
	Wales	0.61–1.2	0.858–1.3	ND–0.1
Mineral	England	ND–1.8	0.9–3.8	0.1–0.6
	N. Ireland	0.8–2.0	0.4–1.2	ND–0.1
	Scotland	ND–2.0	0.4–24.0	ND–1.6
	Wales	ND–0.7	1.1–1.6	0.2–0.3
Non-ferrous metals	England	ND–1.6	0.3–2.29	0.1–0.753
	Scotland	ND–1.1	0.7–1.5	0.2–0.3
	Wales	ND–4.2	0.8–3.0	0.11–2.9
Oil refinery	Scotland	ND–1.68	0.82–1.8	0.063–0.2
	Wales	ND–0.9	0.1–0.7	ND–0.4
Paper	England	ND	0.7–1.0	0.1–0.2
Power station	England	ND–1.43	0.4–4.0	ND–0.4
	N. Ireland	ND–1.9	0.4–1.4	ND–0.2
	Scotland	1.1–1.3	0.7–1.1	ND–1.5
	Wales	2.0–4.1	1.3–2.3	ND–0.3
Steel	England	ND–1.5	0.6–20.6	0.1–11.4
	Scotland	1.96–2.13	3.31–3.54	0.4–0.504
	Wales	ND–2.4	0.6–4.8	ND–6.1
Tar/bitumen	England	ND–1.2	1.8–4.6	0.4–1.2
Textile	N. Ireland	0.4–1.5	0.9–1.7	ND

Location	Country	Se	Mo	W
Rural	England	1.3	0.9–1.0	ND–0.3
	Scotland	3.13	0.984	0.12
	Wales	3.3	1.8	ND
Urban	Scotland	ND	0.8	0.2

(i) Group VIII: Cobalt

Industry	**Country**	**Co**
Chemical	England	7.7–11.2
	Scotland	3.6–14.5
	Wales	6.2–14.2
General	N. Ireland	4.5–14.4
Incinerator sites	England	0.7–14.5
	Scotland	9.6–19.0
	Wales	8.4–19.0
Landfill sites	England	4.8–9.7
	Wales	0.132–8.82
Mineral	England	6.2–18.3
	N. Ireland	2.8–6.9
	Scotland	1.6–8.2
	Wales	4.7–7.4
Non-ferrous metals	England	3.4–12.7
	Scotland	7.0–10.6
	Wales	0.004–35.5
Oil refinery	Scotland	0.518–14.4
	Wales	8.8–12.4
Paper	England	8.7–13.0
Power station	England	2.9–20.9
	N. Ireland	8.9–14.5
	Scotland	5.4–9.7
	Wales	7.7–10.3
Steel	England	5.7–13.4
	Scotland	4.56–5.56
	Wales	2.0–16.9
Tar/bitumen	England	6.4–23.2
Textile	N. Ireland	2.0–10.9

Location	**Country**	**Co**
Rural	England	7.8–8.5
	Scotland	6.6
	Wales	9.0
Urban	Scotland	7.5

Appendix 10 – European soil data

Data from: CEN Soil Team (N30) Date: 19 June 2006

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European Commission, Joint Research Centre, Ispra
Soil and Waste Unit
European Soil Bureau (ESB)
ESB-Working Group

Heavy metal (trace element) content of European soils: results of preliminary evaluation for four Member States (F, DK, G, UK)

France: Denis Baize
Denmark: Henrik Breuning-Madsen
Germany Axel Gorny, Jens Utermann and Wolf Eckelmann
UK: Peter J. Loveland (referred to in UKSHS 7 as McGrath and Loveland 1992)

	Cd	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**Cr**
France (aqua regia extraction)							
No.	4,694	5,079	3,550	5,184	5,105	5,081	–
Minimum	<0.1	0.2	0.01	0.1	0.6	0.4	–
Maximum	17.1	663	11.6	147	1,240	2,707	–
Median	0.3	14.4	0.05	19.1	23.8	57.6	–
France (HF extraction)							
No.	4,378	4,378	3,907	4,363	4,376	4,399	–
Minimum	<0.1	2.3	0.01	1.5	0.1	6.0	–
Maximum	7.0	436.4	7.8	1333.4	1560	2276	–
Median	0.3	12.9	0.05	21.0	27.3	60.0	–
Germany (data transformed to aqua regia extractable)							
No.	1,148	1,145	701	1,149	1,144	1,148	1,095
Minimum	<0.1	1.0	<0.01	<1.0	2.3	4.7	<1.0
Maximum	5.8	129.9	1.2	350.9	279.7	379.9	360.2
Median	0.4	14.4	0.13	16.1	35.3	55.1	18.4
Denmark (digestion with 50 per cent HNO_3 – a much weaker extraction method)							
No.	393	393	393	393	393	393	393
Median	0.2	7.0	0.04	5.0	11.3	26.8	9.9

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