

Contamination of soils in domestic gardens and allotments: a brief overview

B. J. Alloway

Abstract

This overview has been prepared as an introduction to the sources of contaminants in gardens and allotments for the special issue of Land Contamination and Reclamation on the contamination of domestic gardens and allotments.

Soils in domestic gardens are often found to be contaminated with a range of substances and pathogens which could pose a hazard to health. These contaminants include: heavy metals and metalloids, especially lead, zinc, copper and cadmium; organic pollutants such as PAHs and pesticides; asbestos and pathogens. The possible sources of these respective contaminants are discussed and some brief case studies referred to. There are about 15 million houses with gardens in Great Britain, and so this likelihood of soil contamination is highly significant. Children are more likely to be exposed to contaminants in gardens than on industrially contaminated land. Although most garden and allotment soils are contaminated at least to a limited extent, it is often difficult to predict which gardens will be more heavily contaminated through the actions of householders or allotment tenants. Areas affected in the past by atmospheric deposition from major sources of air pollution such as industries or heavy traffic, and gardens of properties developed on contaminated land without precautions to remove contaminants, are more easily identified.

Key words: allotments, asbestos, contamination, gardens, heavy metals, PAHs, pathogens, POPs

1 INTRODUCTION

In almost all residential areas, except possibly, inner cities, houses generally have gardens. These are small areas of open space, usually directly in front and behind the property, which are used for a variety of different purposes including: growing ornamental plants, fruit and vegetables, lawns and patios for relaxation, children's play areas, location for a workshop or garage and storage of large items such as caravans and boats. Gardens contain a much wider range of plant species than natural or semi-natural habitats and tend to include a high proportion of alien species. They are also very important habitats for wild birds. There are estimated to

be around 15 million domestic gardens in Great Britain. In England and Wales gardens and allotments cover approximately 3.2% and 0.07% of the land area, respectively. In the London area alone there are 1.4 million households with gardens and 980 ha of allotments. Therefore, gardens and allotments are highly significant in terms of total land area used and also the numbers of adults and children who come into regular contact with soil.

A survey of allotment holders in England and Wales in 1993, showed that 75% of allotment gardeners were over 45 years old and the older gardeners tended to have the larger plots. The modal size of allotment plots was between 150 and 250 m². All the gardeners grew root crops and green vegetables and 90% of them also grew salad crops (Saunders 1993).

Garden and allotment soils are generally found to be contaminated as a result of pollution from houses, roads and general urban/industrial activity, and partly through the actions of householders and allotment tenants; garden and allotment soils are generally found to be con-

Received June 2004; accepted July 2004

Author

B. J. Alloway, Department of Soil Science, The University of Reading, PO Box 233, Reading RG6 6DW, UK. Email: B.J.Alloway@reading.ac.uk

Table 1. Total concentrations of heavy metals in garden soils in England, Scotland and Wales and London Boroughs

	Number of houses ^a	(Geometric means and ranges, mg kg ⁻¹)		
		Pb	Cd	Zn
All areas*	4127	266 (13 – 14 100)	1.2 (<1 – 40)	278 (13 – 14 600)
London Boroughs	579	654 (60 – 13 700)	1.3 (<1 – 40)	424 (58 – 13 100)

^a Up to 100 houses in each of 50 cities, boroughs, towns or villages in England, Scotland and Wales,

* All study locations excluding hotspots such as mining areas

Cu = 53 mg kg⁻¹ in all areas, 73 mg kg⁻¹ in London Boroughs
(Culbard *et al.* 1988)

taminated with a range of potentially toxic or harmful substances. Potential risks to human health from contaminated gardens and allotments can arise from the pathway of regular consumption of home-grown produce containing elevated concentrations of potentially toxic substances, the ingestion of contaminated soil, either accidentally or intentionally (mainly by children), and the inhalation of contaminated soil particles in house dusts in adjacent properties.

Chemical contaminants frequently found in elevated concentrations in garden and allotment soils include: heavy metals, such as lead, mercury, copper and zinc, and persistent organic pollutants such as polycyclic aromatic hydrocarbons (PAHs). Other common garden soil contaminants which are potentially

hazardous to health include pathogens and asbestos fibres.

2 CONTAMINANTS FOUND IN GARDEN AND ALLOTMENT SOILS

2.1 Heavy metals and metalloids

A survey of heavy metals in more than 4000 domestic gardens and associated house dusts in up to 100 houses in each of 50 cities, towns or villages in England, Scotland and Wales was carried out by Culbard *et al.* (1988). As shown in Table 1, they found that the mean concentrations of lead and zinc were much higher in the gardens of houses in Greater London than for the all

Table 2. Total concentrations of heavy metals in garden and agricultural soils in France, Germany and England/Wales

Soils	(mg kg ⁻¹)				
	Cd	Cu	Ni	Pb	Zn
105 gardens in eastern France ¹					
Mean	1	27.3	19.3	58.7	138
Maximum	5.3	181	56.4	340	518
3624 gardens in Germany ²					
Mean	0.5	24	14	65	151
Maximum	7.3	196	69	627	1035
4127 gardens in England, Wales & Scotland ³					
Geom. mean	1.2	–	–	266	278
Maximum	40			14 100	14 600
18 000 agricultural soils in Germany					
Mean	0.44	15	15	36	67
5692 soils in England & Wales (5 km grid)					
Median	0.9	23	41	74	97

1. Schwartz *et al.* (2000)

2. Größman and Wüsterman (1992)

3. McGrath and Loveland (1992)

of the locations sampled in England, Scotland and Wales, but excluding samples from obviously polluted areas, such as villages with old mine workings.

In general, garden soils tend to contain higher concentrations of lead and zinc than agricultural soils, as shown in Table 2. From this table, it can be seen that the mean values for lead and zinc in gardens in England, Scotland and Wales are much higher than those reported in France and Germany. There are several possible reasons for this, including the age of the houses where the gardens were sampled. Norra *et al.* (2001) found that the mean lead and zinc concentrations in gardens of houses of different ages in Mühlburg/Karlsruhe, south-western Germany, showed a decrease with age of house. The gardens of houses built before 1920 had the highest mean lead values, followed by houses built between 1920 and 1980, and houses built after 1980 had the lowest mean concentrations (160 mg Pb kg⁻¹ pre 1920, 118 mg Pb kg⁻¹ 1920–1980, and 39 mg kg⁻¹ post-1980). From Table 2, it would also appear that, in addition to garden soils, agricultural soils in England and Wales also have higher mean lead and zinc concentrations than those in Germany. The England and Wales survey comprised soils taken on a 5 km × 5 km grid which included sites contaminated from sources such as metalliferous mining or with a long history of heavy applications of sewage sludges.

There are many possible sources of heavy metal and metalloid contamination in gardens and allotments; these include:

- (a) **Previous use of the site** – this could include a history of urban environmental pollution, industrial uses (e.g. brownfield sites), agricultural and horticultural use of the land with associated inputs of heavy metals and metalloids in pesticides, sewage sludge and livestock manures, demolition of previ-

ous buildings on the site and even bombing of buildings during the Second World War. (See Table 7.)

- (b) **Atmospheric deposition** – contaminants in emissions from motor vehicles, domestic and industrial burning of fossil fuels, industry (e.g. metal smelters, foundries), incinerators and dust from nearby contaminated sites may have been deposited on the garden or allotment sites.
- (c) **Particles of paint** – these could be scrapings, fragments and weathered paint emulsions from painted wood on houses and other structures, such as bridges, which fall on to soil and are rich sources of metals such as Pb, Zn, Cd and Cr (see Table 3).

Table 3. Total lead concentrations in garden topsoils (0–5 cm) adjacent to painted wooden houses and controls in Minneapolis, USA

	(mg kg ⁻¹)	
	Painted houses	Non-painted houses
	(n=24)	(n=20)
Median	938	526
Minimum	475	130
Maximum	6150	1840

(Mielke *et al.* 1984)

- (d) **Historic use of contaminated fill for site leveling** – soil, rubble or mineral material from a variety of sources, including wartime bombed areas and demolition sites could have been used to raise the level of the land and fill in depressions. These materials may have contained a wide range of

Table 4. Factors controlling the bioavailability and mobility of heavy metals and metalloids in soils

<p>Soil physico-chemical conditions</p> <ul style="list-style-type: none"> • pH – cations more available at low pH, anions more available at high pH • Organic matter content – many elements are bound to soil organic matter • Calcium carbonate content – free CaCO₃ maintains pH >7 and renders metals less available • % of clay-sized material – metals sorb on to clays • % plaster and concrete present – have effects on the pH and sulphate content • Redox conditions: freely/poorly drained soils – dissolution/precipitation of oxides and sulphides (affect sorptive properties of a soil) <p>Nature of the contamination</p> <ul style="list-style-type: none"> • Forms of metals: particulates, soluble, organically bound (e.g. composts, paint) • Concentrations of other contaminants – antagonistic or synergistic effects on sorption and desorption, uptake by plants, and toxicity in plants and animals.
--

Table 5. Comparison of agricultural, garden/allotment and derelict industrial site soils with regard to factors affecting the behaviour of contaminants

Parameter	Agricultural soil	Garden/allotment soil	Derelict industrial site soil
pH	5 – 8	5 – 8	2 – 13
Organic matter (%)	1 – 10	3 – 30	<1
Clays and oxides	Abundant	Abundant	Variable (often low)
Building rubble	Absent	Low	High
Plant nutrients	Abundant	Abundant	Low
Concentrations of Cl ⁻ & SO ₄ ²⁻	Low	Low	High
Heavy metals/metalloids	<0.01% (<Ksp)*	<0.01 – 0.1% (<Ksp)	<1% (>Ksp)
Organic pollutants	Low	Low	High
Spatial heterogeneity	Low – moderate	High	Very high
Toxicity pathways	Food chain	Food chain, soil ingestion, dermal contact	Inhalation, dermal contact, soil ingestion, ground/surface waters
Ecotoxicity	Low	Low	High

* Ksp = solubility product

Derived from Alloway (2001)

metal and organic contaminants, as shown in Table 6.

- (e) **Bonfires** – fires used to burn wood and other combustible materials can give rise to relatively high concentrations of contaminants in the residual ash. This is usually spread on the garden soil, and can give rise to contamination hotspots. Examples of contaminants are: Pb and Cr from paints, As, Cu and Cr from wood preservatives, and Cd from plastics. There are also instances of ash (containing various contaminants, including radionuclides) from bonfires on industrial sites being collected up and used on allotments.
- (f) **Runoff from metal surfaces** – this could result in relatively high concentrations of Zn and Cd in water dripping from galvanised roofs and stored galvanised sheeting, galvanised fencing and gutters, and Pb from roofing.
- (g) **Use of ash/mineral waste for making paths** – some waste materials, such as incinerator ash, coal ash and metalliferous mine waste are used to make free-draining garden paths. In some cases the phytotoxic effects of the contaminants are exploited to give weed-free paths. Soil under and adjacent to these paths will be significantly contaminated.
- (h) **Burial of metal-containing wastes** – a wide range of waste materials, such as old electric cables, batteries and paint scrapings may have been disposed of by burial in the garden and can be a major source of Pb, Cu and Zn.
- (i) **Composts and fertilisers** – certain fertiliser materials can contain significant concentrations of trace

metals, including: Cd and Zn in phosphatic fertilisers and a wide range of metal and organic contaminants in composts and sewage sludges. In the past, it was sometimes the practice to compost waste and/or by-products from local industries, such as leather (Cr), felt (Hg) and carpet fabric, and these could have added considerable amounts of metals.

- (j) **Pesticides** – compounds containing Pb, As, Cu, Hg and Zn may have been used in significant amounts on annual crops and fruit trees over many years.
- (k) **Sports and hobbies** – airgun pellets, spilled fishing weights, mislaid lead toy soldiers and garden ornaments could give rise to localised high concentrations of Pb.

Table 6. Composition of soils in Berlin containing debris from bombing

Constituent	Mean content	(mg kg ⁻¹)	
		Minimum	Maximum
Lead	330	2.2	3188
Zinc	379	7	3607
Copper	99	4	657
Cadmium	175	<1	757
PAHs (16)	30	<1	644
Sulphate	1522	3	10 000
Phosphate	288	<1	4849
pH (in CaCl ₂)	7.6	6.4	11.2

Mekiffer *et al.* (2000)

The contribution of lead-containing paint to concentrations of this element in garden soils is clearly illustrated by the results shown in Table 3. This source is more important where houses are built entirely of wood, rather than where only window frames and fascias around roofs are painted wood. It has been estimated that in the late 1980s, 11.7 million children in the USA were probably at risk due to exposure to excessive amounts of lead in contaminated garden soils and house dusts (Millstone 1997).

Table 7. Concentrations of PAHs in urban soils in Berlin, Germany

Type of material	(mg kg ⁻¹)	
	Range of PAH concentrations	Range of benzo(a)pyrene concentrations
Debris from bombing (n=53)	0.21 – 643.64	0.03 – 33.30
Building rubble (n=12)	0.2 – 13.73	0.01 – 0.54
Ash (n=13)	0.12 – 1.34	0.02 – 0.05
Waste (n=14)	1.54 – 475.92	0.14 – 13.57
Harbour silt (n=3)	2.53 – 3.14	0.05 – 0.07
Coking plant (n=3)	1.07 – 141.67	0.02 – 2.23

Mekiffer *et al.* (2000)

2.2 Organic pollutants

Garden soils can often be significantly contaminated with a range of organic pollutants, especially in the gardens of old houses in urban areas which will have been a sink for atmospheric pollutants. Some of the sources of organic pollutants, including persistent organic pollutants (POPs) include:

- (a) **Previous use of the site** – various industrial uses of the land, such as dyeworks, petroleum stores, garages and others could have given rise to high concentrations of organic pollutants, pesticide residues and decomposition products from the previous agricultural or horticultural use of the site. Fires and wartime bombing will have led to the accumulation of PAHs and other organic chemicals stored on the sites.
- (b) **Pesticides** – many gardeners use considerable quantities of pesticides. These may accumulate as the original formulations, or their degradation products. In addition, chlorinated pesticide compounds such as 2,4,5-T and 2,4-D will often have contained small but significant amounts of dioxin and/or furan contaminants (PCCD/PCDFs). Tar oils containing PAHs and phenols were often used as winter bark washes on fruit trees.
- (c) **Atmospheric deposition** – these could include emissions from fossil fuel combustion and fires (PAHs), industrial emissions (e.g. PCCD/PCDFs from steel manufacture) and emissions from incineration (PCCD/PCDFs).
- (d) **Leakage, spillages and dumping of hydrocarbons** – leaking of domestic heating oil from storage tanks and dumping of waste car oil in gardens, or building on old garage sites can all result in significant hydrocarbon contamination of garden soils.
- (e) **Wood preservatives** – either the spillage or wash-off of creosote (PAHs) and chlorophenolics on sheds and fencing.
- (f) **Composts** – can contain a range of organic pollutants.
- (g) **Waste dumping** – burial of waste containing POPs.
- (h) **Bonfires** – burnt wood and plastics can lead to significant concentrations of PAHs and PCCD/PCDFs in the ash.

2.3 Mineral fibres

Fibres of minerals which pose a possible risk to health, such as asbestos, can also be important contaminants in garden soils, but the areas affected are likely to be much smaller than for most of the other types of contaminants discussed here. Sources of potentially hazardous mineral fibres can include:

- (a) **Previous use of the site** – such as industrial use where asbestos was used for insulation, storage of asbestos, former garage sites contaminated with dust from brakes and clutches and former landfills may also be a significant source of these fibres.
- (b) **Atmospheric deposition** – from docks and railway goods yards where asbestos was handled, and from demolition sites when asbestos insulation was dispersed into the environment in the days before rigorous controls were introduced.
- (c) **Burial of waste** – certain decorating materials and insulation containing asbestos may have been buried in gardens or used to construct paths.
- (d) **Car washing** – asbestos from brake dust may reach the garden soil.

2.4 Pathogens

Garden soils can become a reservoir of pathogens which could pose a risk to the health of both children and adults. The pathogens involved can range from bacteria, such as *E.coli* and *Salmonella* species, to the eggs and larvae of parasites such as *Toxocara* species and tapeworms.

Sources of pathogens in gardens can include:

- (a) **faeces** – from cats, dogs and birds (especially if poultry kept);
- (b) **burial of dead animals** – either of livestock during former agricultural use of the site or the burial of pets in the garden;
- (c) **sewage sludge** – where it was been applied to the land when it was in agricultural use; little is likely to have been used in gardens;
- (d) **atmospheric deposition** – from nearby livestock industry (e.g. poultry);
- (e) **flooding of land** – with river water containing raw sewage.

2.5 Discussion of different contaminants

2.5.1 Heavy metals and metalloids

All soils contain trace metals derived from the parent material and, in most cases, also from environmental pollution, although concentrations vary greatly. Some soil parent materials can be geochemically enriched in certain elements. For example, marine black shales can be significantly enriched in As, Cd, Pb, Mo, Hg, U, V and Zn. Even though not significantly contaminated from an extraneous source, soils developed on these shales or other rock types with elevated concentrations of some of these elements could still pose a possible hazard to health. On the other hand, soils developed on many sandstone formations or sandy drift will normally tend to have relatively low concentrations of many elements, at least in an agricultural context, but contamination could also have resulted in even these soils having relatively high concentrations of various elements.

The factors controlling the bioavailability and mobility of heavy metals and metalloids are shown in Table 4 (Alloway 1995). Generally speaking, metal cations, such as Cd^{2+} and Cu^{2+} are more available in acid or sandy soils with low clay contents. Their uptake by plants can often be reduced by liming the soil to raise the pH. However, individual elements differ considerably in their soil-plant transfer coefficients, and the general order of decreasing transfer coefficients is: $\text{Cd} > \text{Zn} > \text{Cu} > \text{Pb} > \text{As} > \text{Ba}$ (Kabata-Pendias and Pendias 1992).

Some of the key differences in the soil properties between agricultural soils, garden and allotment soils and material on derelict industrial sites are shown in Table 5. It can be seen that garden soils have a lot of similarities with agricultural land, but both of these tend to differ markedly from derelict industrial sites. Apart from the higher degree of contamination, the presence of concrete and building rubble, and absence of the original topsoil, help to explain the more extreme

range of physico-chemical properties in the industrial sites.

It is usually found that the concentrations of most metals/metalloids are higher in the surface soil (0–15 cm) than in deeper layers. This is due to greater retention in the humus and atmospheric deposition of contaminants on to the surface. However, if higher concentrations are found at depth, the site could have received soil or fill from an extraneous source which was significantly contaminated, or it could be underlain by a former landfill or waste tip. From Table 6, it can be seen that soils in Berlin which contained debris from wartime bombing had some very high concentrations of cadmium and other metals (Mekiffer *et al.* 2000). Garden soils with these concentrations of heavy metals might pose a significant risk to human health if they were used for growing vegetables or for children to play in.

All soils will contain all elements, and appropriate risk assessment procedures should be undertaken to determine if elevated concentrations represent unacceptable risks to humans and other receptors.

Some urban areas and rural villages with a history of metalliferous mining may have soils which are enriched in several elements due to a combination of the presence of weathering ore under the soil, contamination from solid and liquid wastes from mining and possible deposition of metal aerosols and dusts from smelting nearby. However, the availability of the metals in these mining-contaminated soils will depend on the form in which they occur. For example, phosphate forms of Pb, such as chloro-pyromorphite, may be relatively insoluble and unavailable to plants (Cotter-Howells and Thornton 1991). However, the Pb may still be bio-available through soil ingestion.

2.5.2 Organic pollutants

Unlike metals, all organic molecules are ultimately decomposable. However, some organic contaminants can persist for a long time (tens or hundreds of years). Persistent organic pollutants (POPs) include: PAHs, PCBs, PCDDS (dioxins) and PCDFs (furans), phenols, chlorophenols and BTEX (benzene, toluene, ethyl benzene and xylene) and insoluble pesticide residues (e.g. aldrin, dieldrin, DDT, malathion, toxaphene).

The analysis of organic pollutants is generally much more time-consuming and expensive than it is for metals, and this often limits the number of samples which can be analysed. Indirect methods, including total organic carbon, soil colour and odour, are sometimes used as surrogates to determine the presence of high concentrations of organic molecules such as petroleum hydrocarbons. Generally, organic pollutants tend to accumulate in the humus-rich topsoil, but dense, non-

aqueous phase liquids (DNAPLs) will migrate down through voids to the lower levels of subsoil, where they may enter an aquifer or accumulate above an impermeable layer. However, DNAPLs are less likely to occur in gardens and allotments than in contaminated industrial sites. Petroleum hydrocarbons are the most common organic pollutants in industrially contaminated land. They vary in their toxicity, but they are a fire hazard, can be toxic to plants and can contaminate groundwater.

Soils in old urban areas have significantly higher concentrations of PAHs and soot than newly built-on agricultural land. These will have been derived from domestic coal fires and atmospheric pollution from vehicles and industry. From Tables 6 and 7, it can be seen that wartime bombing and associated fires and explosions can give rise to hotspots with high concentrations of PAHs and, possibly also industrial chemicals. Post-war site clearance and reconstruction may have led to stratification of subsurface materials (with distinct layers differing in texture and composition) in affected urban areas. If these stratified layers are disturbed and mixed up during subsequent excavation, there is a possibility of some formerly immobile contaminants being rendered more mobile and bioavailable.

The organic contaminants in topsoils pose a greater potential risk of health hazards from soil ingestion and dermal contact than those present in the subsoil. Poultry kept in gardens could also be an important pathway of lipophilic POP contaminants in soil to humans via eggs.

2.5.3 Mineral fibres

Unlike the heavy metals, metalloids and organic pollutants, mineral fibres, such as those of asbestos, are most hazardous to health from inhalation when they are re-suspended in air. However, soil ingestion or intake through drinking water is also a possible pathway. Resuspension is most likely to occur when the soil is dry and is disturbed or eroded by wind. These fibres do not readily undergo decomposition nor take part in chemical reactions. Soils which have been identified as being heavily contaminated with asbestos will normally have to be removed and replaced by clean soil. However, covering less seriously contaminated soils with clean soil and/or keeping the soil surface protected from disturbance and erosion by paving over to create a patio or yard, is an alternative approach.

2.5.4 Pathogens

Some pathogens can persist as spores or eggs in soil for many years. Cat and dog faeces can be a source of several hazardous pathogens (e.g. *Toxocara*). Poultry kept

in gardens can be a source of pathogens such as *Salmonella* spp. Gardens and allotments on former agricultural land can also have been contaminated with pathogens of farm livestock (e.g. anthrax spores, *Salmonella*, etc.) or from untreated sewage. Routes of infection include: soil ingestion, cuts and grazes, dermal contact and inhalation of soil particles in dust.

3 TYPICAL CAUSES OF SERIOUS CONTAMINATION OF URBAN GARDEN AND ALLOTMENT SOIL

3.1 Building on former landfills and made land

In Mundelstrup, near Aarhus, in Denmark, it was found that the soils in the gardens of 30 houses built on fill from an old sulphuric acid and fertiliser factory had very high concentrations of lead ($< 67\,563 \text{ mg Pb kg}^{-1}$) and arsenic ($< 5481 \text{ mg As kg}^{-1}$). A remediation programme was carried out between 1990 and 1992 when around $50\,000 \text{ m}^3$ of contaminated soil were removed and disposed of in a specially constructed landfill, and clean soil from this excavation was used to rebuild the gardens (Clement *et al.* 1995). All the areas were cleaned up to have soil lead concentrations of less than 40 mg Pb kg^{-1} .

At Lekkerkerk, near Rotterdam, the height of the land was raised by 3.5 m using fill contaminated with paint solvents and heavy metals to build new houses. In 1981, 200 houses had to be evacuated and $87\,000 \text{ m}^3$ of material removed from under the houses (including 1652 drums of wastes).

3.2 Industrial accidents causing atmospheric dispersion of contaminants

In 1976, in Seveso (Italy) an explosion at a pesticide manufacturing plant caused widespread dispersion of PCDDs (dioxins) and other persistent organic pollutants affecting 1.3M ha ($< 20 \text{ mg TCDD m}^{-2}$ in soil) (Pocchiari *et al.* 1983).

In Cheshire (UK), a fire in a solvent recovery works resulted in a high level of soil contamination by solvents, benzene ($< 208 \text{ mg kg}^{-1}$), PCBs (1160 mg kg^{-1}) and PCDD/PCDFs (up to 168 mg kg^{-1} TEQ, which was one of the highest concentrations found in soils). Guinea pigs kept in the area died from PCDD toxicity (Craig and Grzonka 1994).

3.3 History of chronic atmospheric emissions and deposition of pollutants from industry

Steel manufacturing has given rise to emissions of PCDD/PCDFs from sintering plants, and dusts containing high concentrations of several heavy metals can be emitted from electronic arc furnaces used for smelting

scrap. Non-ferrous metal smelters can give rise to the atmospheric dispersion of aerosols and dust-sized particles containing As, Cd, Cu, Hg, Pb, Tl and Zn. Emissions from welding and metal casting works can contain Cd, Pb and Zn, etc. in fumes and solid/liquid wastes. All of these industrial sources can give rise to significant contamination of both agricultural and garden soils in the vicinity of the works, especially downwind.

Waste incineration can emit significant concentrations of Cd, Pb, As, PCDD/PCDFs and other compounds into the atmosphere if the pollution control procedures are not efficient. In the past, there have been cases of scrap yards (or metal recycling industries) causing significant soil contamination in their vicinity from the reclamation of lead from old car batteries, which led to atmospheric pollution with Pb and As. The burning of old plastic-coated cables to reclaim their copper cores may have caused atmospheric pollution by PCDD/PCDFs. Additional soil and groundwater contamination is possible from particles of corroded metal and paint, and leakage of fuels and lubricants from old vehicles (NADPLs, Pb) and insulating fluid from transformers/capacitors (PCBs). In most of these cases, it is highly likely that soils are often contaminated to considerable depths and with a very high degree of spatial heterogeneity.

3.4 Redeveloped brownfield sites (and previous business premises)

In many countries, strict regulations are enforced with regard to maximum permissible concentrations of contaminants on brownfield sites redeveloped for housing (e.g. Part IIA of the Environmental Protection Act 1990). However, before the possible hazards of contaminated land to human health were fully appreciated, many former industrial sites were redeveloped, with relatively high concentrations of contaminants remaining in the garden soils. At many former industrial sites in urban areas, the original soil will probably have been removed and sold off site, so the material at the surface is likely to comprise a mixture of the original subsoil, demolition rubble from previous structures on the site, imported fill and, possibly imported topsoil. Even when a cosmetic layer of topsoil is placed over building rubble, some contaminants in the rubble can still migrate into the rooting zone of garden plants by capillary rise, and also accumulate in the topsoil.

Examples include:

- (a) Former gas works sites which are contaminated with PAHs, phenols, cyanides and metals (such as Kralingen in the Netherlands).

- (b) Printing works sites contaminated with solvents and inks containing organic pollutants and lead from type.
- (c) Sites of former garages and filling stations which are contaminated with petroleum hydrocarbons constitute a hazard from high soil calorific value, groundwater pollution with hydrocarbons and lead contamination from the lead additives in petrol.
- (d) Textile and dye works sites contaminated with both organic pollutants (including TCE, PVC, PCDDs) and inorganic substances such as Cd, Hg, Br and F.
- (e) Timber yards contaminated with wood preservatives including: chlorophenols, creosote (PAHs), and Cu, Cr and As.
- (f) Tannery sites, which used to be found in many small towns and country villages, can be contaminated by Cr, organic pollutants and pathogens.

3.5 Emissions from road traffic

Roads in urban areas and major trunk roads can be sources of several soil contaminants, including:

- (a) **metals** such as Pb, Zn, Cu, V and Mo from vehicle exhausts, tyre particles, corrosion of vehicle body work and road markings, and brake and clutch dust;
- (b) **petroleum hydrocarbons** (both in volatile and droplet forms) from unburnt fuels;
- (c) **persistent organic pollutants**, including PAHs and various other gaseous combustion products;
- (d) **particulates**: aerosol-sized particles from exhausts, especially PM_{2.5} from diesel fuel, Pt from catalytic converters and asbestos from brakes and clutches.

4 CONCLUSIONS

Several studies have concluded that the most significant hazards from contaminants in garden soils are likely to be from lead, cadmium, mercury and PAHs.

Soil ingestion by children in gardens adjacent to houses, constitutes a more important pathway than consumption of vegetables grown on contaminated soils. House dusts frequently show a significant correlation with the composition of garden soils. The presence of pets in houses has also been found to strengthen this correlation because they carry contaminant particles into the house from either the garden or the street.

Apart from large areas of contamination due to atmospheric deposition from a historic source like a major industry (e.g. smelter), or from building on contaminated soil (such as former landfills), contamination

of individual gardens is difficult to predict. This is due to the wide range of possible contaminants which householders, allotment tenants and small localised sources of pollution can introduce to individual gardens. The only way in which contamination can be detected is by soil and/or produce testing in individual gardens, and this would be very expensive.

Where garden soils are found to be contaminated, dietary exposure can be prevented by not growing food crops in the soil, possibly using grow-bags or tubs of clean soil instead. Where the contamination is not severe, it would be possible to grow crops which accumulated relatively low concentrations of potentially toxic elements and avoid the high accumulating crops such as spinach and lettuce. Soil ingestion and inhalation can be prevented by covering the contaminated soil with either a cover of clean soil (usually with a protective cover over the contaminated soil to prevent digging) or paving with an impermeable surface. In extreme cases, the soil may need to be removed, but this is often difficult due to problems of access and also the risk of dispersion of contaminants during the clean-up process. However, it is necessary for site-specific risk assessments to be carried out so that the appropriate form of remediation can be determined.

Contaminated garden soils could possibly affect the health of a large number of adults and children and therefore it is important that research and development is carried out on risk assessment and also on measures for the mitigation of contamination.

5 REFERENCES

- Alloway, B.J. (ed.) (1995) *Heavy Metals in Soils* (2nd ed.). Blackie Academic and Professional, Glasgow
- Alloway, B.J. (2001) Soil pollution and land contamination. In Harrison, R.M. (ed) *Pollution: Causes, Effects and Control* (4th ed.), pp. 352–377. Royal Society of Chemistry, Cambridge
- Clement, P., Olsen, N.J. and Madsen, P. (1995) Mundelstrup, Denmark: the clean-up of a contaminated town. *Land Contamination and Reclamation*, **3**, 39–46
- Cotter-Howells, J. and Thornton, I. (1991) Sources and pathways of environmental lead to children in a Derbyshire mining village. *Environmental Geochemistry and Health*, **13** (2) 127–135
- Craig, T. and Grzonka, R. (1994) A case study of land contamination by solvents, polychlorinated biphenyls and dioxins. *Land Contamination and Reclamation*, **2**, 19–26
- Culbard, E.B., Thornton, I., Watt, J., Wheatley, M., Moorcroft, S. and Thompson, M. (1988) Metal contamination in British urban dusts and soils. *Journal of Environmental Quality*, **17**, 226–234
- Größman, G. and Wüsterman, M. (1992) Belastungen in Haus- und Kleingärten durch anorganische und organische Stoffe mit Schadstoffpotential. *Forschungsbericht 1160868*, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit
- Kabata-Pendias, A. and Pendias, H. (1992) *Trace Elements in Soils and Plants* (2nd ed.). CRC Press, Boca Raton, Fla
- McGrath, S.P. and Loveland, P.J. (1992) *Soil Geochemical Atlas of England and Wales*. Blackie Academic and Professional, Glasgow
- Mekiffer, B., Renger, M. and Wessolek, G. (2000) Contamination of urban soils – first results from a databank. In Burghardt, W. and C. Dornauf (eds.) *Proc. 1st Int. Conference on Soils of Urban, Industrial, Traffic and Mining Areas, Essen, Germany, July 2000*, Vol. III, pp. 593–598
- Mielke, H.W., Blake, B., Burroughs, S. and Hassinger, N. (1984) Urban lead levels in Minneapolis: the case of the Hmong children. *Environmental Research*, **34**, 64–76
- Millstone, E. (1997) *Lead and Public Health*. Earthscan, London
- Norra, S., Weber, A., Kramar, U. and Stüber, D. (2001) Mapping of trace metals in urban soils – the example of Mühlburg/Karlsruhe. *Journal of Soils and Sediments*, **2**, 77–93
- Pocchiari, F., Di Domenico, A. and Silano, V. (1983) Environmental impact of the accidental release of tetrachloro-dibenzo-p-dioxin (TCDD) at Seveso (Italy). In Coulson, F. and Pocchiari, F. (eds.) *Accidental Exposure to Dioxins*, Academic Press, New York
- Saunders, P. (1993) *Allotment Gardeners in England and Wales: Report of a National Sample Survey*. National Society of Allotment and Leisure Gardeners Ltd., Corby
- Schwartz, C., Fetzer, K.D., Kubiniok, J. and Morel, J.L. (2000) Availability of pollutants in garden soils. In Burghardt, W. and Dornauf, C. (eds) *Proc. 1st Int. Conference on Soils of Urban, Industrial, Traffic and Mining Areas, Essen, Germany, July 2000*, Vol. II, pp. 485–490