Metal contamination of urban soils in the vicinity of a municipal waste incinerator: one source among many

David L. Rimmer¹, Catherine G. Vizard², Tanja Pless-Mulloli², Ian Singleton³, Vivienne S. Air⁴ and Zoe A. F. Keatinge³

¹School of Civil Engineering & Geosciences, ²School of Population & Health Sciences, and ³School of Biology, Institute for Research on the Environment and Sustainability, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK and ⁴Public Health & Environmental Protection, Newcastle City Council, Civic Centre, Newcastle upon Tyne NE1 8PR, UK

*Corresponding author: +44 (0)191 222 6916 (tel.); +44 (0)191 222 5431 (fax);
david.rimmer@ncl.ac.uk

Address for proofs: School of Civil Engineering & Geosciences, Drummond Building, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK
Abstract

Concern from local residents about possible contamination with metals and PCDD/F (dioxins and furans) from fugitive and stack emissions from the Byker municipal solid waste incinerator in Newcastle upon Tyne led the City Council to initiate a study of the concentration of these pollutants in soils. We report here the results for the metals and arsenic. Soils were sampled at distances up to 2.25 km from the incinerator stack. The intensity of sampling in concentric zones was four times greater in the northeast (down-wind) direction, and twice as great in the northwest and southeast directions, compared to the southwest (up-wind) direction. In total 163 samples were collected and analysed for total As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn. Concentrations were generally elevated above background levels, but were typical of those found in other urban areas. For As, Cd, Cu, Hg, Pb, and Zn, contamination hotspots were identified. These were spread throughout the sampling area, and there was no evidence of greater concentrations down-wind of the incinerator compared to other directions, nor of any trend in concentration at increasing distance from the incinerator. We concluded that metal contamination resulting from the incinerator could not be detected in an environment with generally elevated concentrations. Potential sources for many of the hotspots of contamination were identified in a survey of historic land use based on maps of the locality dating back to 1856. Detailed investigations of particular areas with serious contamination will now be undertaken by the local authorities using the CLEA (Contaminated Land Exposure Assessment) model.

Author Keywords: urban environment; incinerator emissions; metal contamination; soils
1. Introduction

Some municipal waste incinerators are located in areas of high population density, and their potential to release contaminants makes the siting of them a matter of intense debate. Metals in particular can be emitted into the atmosphere both from the chimney stack and as fugitive emissions from such incinerators (Feng et al., 2000 and Morselli et al., 2002). This is because metals and their compounds are present in the waste, for example, in lead-based paints, in batteries, and galvanised sheets (Williams, 1994). The extent of evaporation of these metals in the incinerator furnace depends on complex interrelated factors, such as operating temperature and aeration status. With the exception of mercury, the amounts of metals released in stack gases have decreased markedly over the past decade due to improvement in air pollution abatement technology (Allsopp et al., 2001). However, there is still concern as current emissions add to pre-existing concentrations, accumulated in the past when regulation was less effective, and thereby increase risk to humans. Metals can exert a range of toxic effects, including neurological, hepatic, renal, and haematopoietic ones. Ill-health has been reported among populations acutely and chronically exposed to metals, particularly cadmium, mercury and lead (for example, the Port Pirie study in Australia, Tong et al., 1996). Identifying populations likely to be at risk from point sources of pollution, such as incinerators, has been the focus of a recent paper by Williams and Ogston (2002).

Municipal waste incinerators are likely to be one of a number of sources of contamination that have caused urban soils to have generally greater concentrations of metals than those in rural areas (Hutton et al., 1988). In his 1991 review, Thornton listed the potential sources of contamination in soils to include: household and municipal waste disposal, atmospheric emissions from traffic and industrial sources, metal smelting, and manufacturing. Contamination has to be assessed at a particular location against knowledge of the
background concentration of metals in the soil arising from the geological materials from which it has formed. In the UK such information has been obtained by a number surveys, some of which were based on stream sediments (e.g. Webb et al., 1978) and others on soils directly (e.g. McGrath & Loveland, 1992).

On some sites, the extent of contamination may be sufficient to pose a hazard to human health or the environment. The assessment of risk to human health in England and Wales is currently carried out using the CLEA (Contaminated Land Exposure Assessment) model (Environment Agency, 2002a and b). The CLEA model assumes that land use is in one of three categories: residential; allotments; commercial/industrial. There are ten pathways of human exposure to soil contaminants included in the model, for example outdoor ingestion of soil, consumption of home-grown vegetables, skin contact with outdoor soil. The conceptual exposure model selected for each land use, as well as the chemical properties and the toxicology of the given contaminant, is dependant upon the choice of pathway. Estimates are made of contaminant intake from soil as a function of the contaminant concentration and the potential exposure of adults and children living, working and playing on the land. Soil guideline values are derived by comparing the calculated intake with Tolerable Daily Intake (TDI) or Index Dose. The guideline values are ‘intervention values’ i.e. indicators that there is an unacceptable risk to the health of site users where soil contaminant concentrations above the guideline value are present and that further investigation and/or remediation is required.

A number of earlier studies on the metal contamination of soils arising from waste incinerators have been published. In the UK these include those by Hutton et al. (1988), Abbott et al. (1997), and Collett et al. (1998). Two studies based on incinerators in Spain used repeat samplings over a number of years in order to detect changes in soil metal
concentrations that might have been attributable to emissions from the plants (Meneses et al., 1999 and Llobet et al., 2002).

The Byker incinerator is located in Newcastle upon Tyne, and between 1979 and 1998 it produced and burnt refuse-derived fuel (RDF) to generate heat and power. RDF production involved mechanically sorting municipal waste to obtain recyclable metals and glass and to remove any unwanted material, then shredding, pelleting, and drying the remaining combustible waste. The annual throughput of RDF was approximately 30,000 tonnes. Analyses of the RDF over the period 1993-98 showed that its mean metal content (in mg kg\(^{-1}\)) was: As 42, Cd 1.3, Pb 31, and Hg 3.7. The total metal content, which would also have included Cr, Cu, Mn, Ni, and Zn, was 278 mg kg\(^{-1}\) on average. The air pollution abatement equipment at the Byker plant was a dry lime scrubber and a bag filter. Releases to air were also reported between 1993 and 1998 as combined values for: As and Ni (5.71 kg year\(^{-1}\)); Cr, Cu, Pb and Mn (49.1 kg year\(^{-1}\)); and Cd and Hg (4.25 kg year\(^{-1}\)).

Over the past five years a number of studies have been undertaken in relation to soil contamination arising from the operation of the Byker plant. In 1999 local residents raised concerns about incinerator ash from the plant, which was being used on footpaths in local allotments. In response a study was undertaken to identify any health hazard, which might have arisen from this practice (Pless-Mulloli et al., 2000). Because this revealed contamination in the footpaths with both metals and PCDD/F (polychlorinated dibenzo-p-dioxins and furans), two follow-up studies were conducted (Pless-Mulloli et al., 2001a and b) to identify whether any transfer of these had occurred from ash on footpaths into adjacent soil in allotment gardens (ash-to-soil transfer), and to assess transfer of PCDD/F and metals from ash and soil into vegetables. These studies showed considerable soil contamination with
metals, but no clear link to the use of the ash, and very little evidence of transfer of metals from soil into vegetables. Finally a detailed study of one allotment site (Walker Road, situated adjacent to the Byker plant) was carried out (Pless-Mulloli et al., 2002 and 2004). The aims of this were to assess the extent of contamination of soil with both PCDD/F and metals from fugitive and stack emissions from the incinerator. This work produced little evidence to link the soil contamination in the allotment to its proximity to the incinerator.

The current project (Vizard et al., 2003) also aimed to assess the extent of contamination of soil with PCDD/F and metals from fugitive and stack emissions from the Byker incinerator. The area considered extended to a distance of 2.25 km from the plant in all directions. We report here the results for metal contamination. To help interpret the data, an extensive survey of historic land use was carried out using maps of the area dating back to 1856.

This is the first large-scale study of metal contamination arising from an incinerator in an urban environment in the UK since Hutton et al. (1988) published their work on cadmium and lead in the vicinity of an incinerator in north London. Here, in addition to Cd and Pb, we present data for As, Cr, Cu, Hg, Ni, and Zn. This study has also allowed us to build on valuable earlier work on the metal contamination of soils in the Tyneside area (Aspinall et al., 1988; Mellor, 2001 and Mellor & Bevan, 1999).

2. Materials and Methods

2.1. Soil sampling

The area around the incinerator plant was divided into four sectors (NE, SE, SW, and NW) and into distance bands of 50 m up to a distance of 750 m, and thereafter into bands of 250 m up to a distance of 2.25 km (Fig. 1). Any effects of the incinerator were predicted to be
greatest in the NE sector and least in the SW, because of the dominant south-westerly wind direction. This prediction was based on the deposition pattern obtained from dispersion modelling, using the model ADMS-3.1, which was run in November 2001. Therefore the sampling frame was designed to sample from three sites within each distance band in the NE sector, two within each band in the NW and SE sectors, and one within each band in the SW sector. All sampling sites were on land with public access. The locations were randomly generated using geostatistical software (S-Plus 6). If the randomly generated sites were located on buildings or roads, or in areas without public access, they were moved to the nearest area of public open space (‘judgemental’ sites). Some sampling sites were found to be unsuitable when visited, usually because of poor access due to being overgrown with shrubs and undergrowth. These sites were relocated and also denoted as ‘judgemental’. The sampling frame therefore was overall random within a targeted framework. Out of a total of 163 sites, 65 were ‘random’ and 98 were ‘judgemental’.

An area of 50 m by 50 m centred on each site formed the basis for sampling. Soil cores were taken (5 cm diameter and 5 cm depth) at between two and eight points, depending on the proportion of public open space it contained. The soil cores were combined to give a composite sample for each site. Soil samples were air-dried and any plant material (roots, leaves) were removed manually and the soil sieved to < 2 mm. Previous soil studies in Newcastle (Mellor & Bevan, 1999 and Mellor, 2001) have reported soils to be slightly acidic (mean pH 5.5-6.1). In related work, based on a subset of 16 of the present 163 samples, the mean pH was found to be 6.7 (Z.A.F. Keatinge, unpublished data).
2.2. Analyses

The following elements were analyzed: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn). Microwave digestion (MLS-1200 Mega) was carried out over 30 min on the soil samples (approximately 0.5 g) with 10 ml of a mixture of concentrated (65%) nitric acid and 30% hydrogen peroxide. The concentrations of metals in the digest were determined by atomic absorption spectroscopy (AAS, Unicam M series) using either graphite furnace (GF 95) or flame methods. Mercury was determined by AAS using the cold vapour technique (Unicam VP 90). For quality control a reference material (BGR CRM 141 R, calcareous loam soil) was used and analyzed once every 10 soil samples. The typical recovery percentage for "BGR CRM 141 R" is 85-110%. The analyses were carried out at the Ergo Laboratory in Hamburg, Germany.

2.3. Historic and current land use

The GIS package Arcview 3.1 was used to view and reproduce ‘Landmark’ historic maps held by Newcastle City Council and Gateshead Council. Maps were reproduced from Ordnance Survey Historical Data for the epochs 1856-1895, 1895-1898, 1916-1920, 1932-1942, 1952-1963, and 1965-1984.

Industries that are known to contribute substantial environmental pollution (‘Part A’ industries) are regulated in England and Wales by the Environment Agency (EA). A search of the EA pollution inventory database was used to identify such industries within an 8-km radius of Byker reclamation plant. Industrial plants that pollute to a lesser extent (‘Part B’ industries) are regulated by the local authorities. Information on them was obtained from the Newcastle City and Gateshead Councils.
3. Results and Discussion

3.1. Concentrations of arsenic and metals

Mean, median, and the range of concentrations of arsenic and metals over the survey area are shown in Table 1. The distribution of concentrations was skewed by a small number of large values (contamination hotspots). The extent of this skewness was shown by the differences between the mean and the median values. The difference (expressed as a percentage of the median value) was greatest for Cu (202%) and Cd (132%) and least for Cr (8%) and Ni (15%). A similar picture was obtained from examining the ranges of the concentration values for each element. Proportionately (the maximum value as a multiple of the minimum value) Cd (695) and Cu (605) had the largest ranges, and Cr (10) and Ni (15) had the smallest ranges.

Based on these findings, there appeared to be serious contamination hotspots for Cd and Cu, less serious ones for As, Pb, Hg and Zn, whereas contamination with Ni and Cr was more evenly distributed without hotspots. By contrast the normal range of concentration of these elements in UK agricultural soils has been reported to span one order of magnitude only (Archer and Hodgson, 1987).

In order to assess the distribution within each sector, the concentrations for each metal were plotted as a function of distance. As examples, Figs 2 and 3 show the lead and chromium concentrations. Lead was chosen as being typical of those metals showing contamination hotspots (Fig. 2), and chromium, because they were not evident (Fig.3).

The seriousness of the contamination was also assessed in terms of the number of samples exceeding regulatory guideline values, such as the soil guideline values (SGV) derived by the CLEA model (Environment Agency, 2002a and b). This comparison is made in Table 1; it shows that the most serious contamination was for As, Cd and Pb, and that there were no, or
few, exceedances for Hg, Cr and Ni. The quantitative generic SGVs quoted were provided by EA/DEFRA, based on standard assumptions for soil properties, contaminant behaviour, human activity and contaminant toxicology. These guidelines provide a transparent and consistent approach and can help to identify sites which may need a greater level of assessment. As the model parameters for individual sample sites in this study have not been altered, the soil guideline values may be considered purely as a guide, or a point of comparison, rather than an absolute estimation of site specific values.

3.2. Evidence for increased contamination due to incinerator emissions

It was expected that deposition from the stack and fugitive emissions of the incinerator would lead to greater concentrations in the north-east sampling sector than in other sectors (see soil sampling methodology above), and that there might be a gradient in concentration at increasing distance from the incinerator. However, the data in Table 2 show that the north-east sector had in all cases the lowest mean concentration among the four sectors, and Figs 2 and 3 show no gradient away from the incinerator. There was therefore no evidence that the incinerator emissions have had a measurable effect on the average soil contamination within its vicinity. It appears from the data for mean concentrations in Table 2 that the most seriously contaminated sector is that to the south-west of the incinerator with the greatest values for all of the analytes, except Cd and Cr. A detailed examination of the individual sampling points showed that this sector contained a number of contamination hotspots. As this sector had the smallest sampling density (one sample from within each distance band, see soil sampling methodology above), these hotspots will have greatly increased the mean value. However, the median values showed that while the south-west sector had the greatest concentrations for As, Cu, Pb, and Hg, the south-east sector had the greatest concentrations of the remaining elements (Cd, Cr, Ni and Zn).
In some areas CLEA guideline values were exceeded for a number of heavy metals. For example, groups of sampling sites in the SW and NW sectors had large concentrations of arsenic, zinc, mercury, and nickel and the group in the SW sector also had high concentrations of chromium, lead and copper. An asphalt works was located very near to the sites in the NW until the mid-1960s, and British Engines Ltd, an engineering company that manufactures pumps and valves and has a metal foundry, has been located there since the 1920s. Tyne Manure and Chemical Works, a cattle sanatorium, and Tyne Mill were all located very close to the sample sites in the SW. Of these, the chemical works is most likely to have contributed to the soil metal load.

The Walker Road allotment site in the SE sector was contaminated with both lead and copper. This area included the former Dents Hole Quarry until about 1936. This was then land-filled, and therefore subject to contamination from the wastes deposited there. In addition agro-chemical use in the gardens by allotment holders may have increased the concentrations of copper and zinc.

3.3. Comparison with background concentrations

For As, Cd, Cr and Ni, the mean concentrations for soils sampled in the present study were close to, or within, the range for background concentrations in UK soils (Table 3). However for Cu, Pb, Hg and Zn the mean values were considerably elevated above background. A comparison of concentrations with those in the underlying geological material showed a similar picture (Table 3).
3.4. **Comparison with other studies in the Newcastle area**

Data from soils sampled for earlier studies in Newcastle are compared to those found in the present study in Table 4. The Walker Road allotment site generally had the greatest mean concentrations, while the data for the other allotment sites was similar to the concentrations found in the present study. The special circumstances at the Walker Road site have been briefly discussed above and have been reported more fully elsewhere (Pless-Mulloli et al., 2004).

The data for lead from the catchments of the Wallsend and Ouse Burns and for zinc in the Wallsend Burn catchment showed generally smaller concentrations. In the case of the Ouse Burn catchment, this is explained because the area extended outside the city; but even so the concentrations were still greater than the typical background concentrations for UK soils (Table 3).

3.5. **Comparison with other studies in the vicinity of incinerators**

In earlier studies in the UK, Hutton et al. (1988), who measured Cd and Pb in soils in the vicinity of an incinerator in north London, concluded that, in comparison to observed background concentrations, there was “neither a marked, nor extensive, cadmium and lead contamination downwind of the incinerator”. Abbott et al. (1997) who studied a wide range of metals near to four incinerators in Hampshire, and Collett et al. (1998) who reported their results for cadmium and lead near an incinerator in Scotland, found that, with the exception of lead in the Scottish study, there was no evidence that the incinerators had significantly altered metal concentrations in surrounding rural soils.
Two studies based on incinerators in Spain used repeat samplings over a number of years in order to detect changes in soil metal concentrations that might have been attributable to emissions from the plants (Meneses et al., 1999 and Llobet et al., 2002). Despite analysing for a wide range of metals few significant changes could be detected. At one site the concentrations of beryllium and nickel increased in the soils between 1996 and 1997 as a result of the incinerator emissions (Meneses et al., 1999). At the other site reductions in cadmium and lead concentrations in the soils were detected following the installation of abatement equipment (Llobet et al., 2002). It was further concluded that other sources of metal contamination were probably masking other improvements resulting from the emission reductions.

For most of the metals and for As the concentrations in the present study were greater than in earlier studies, where soils were sampled in the vicinity of incinerators (Table 5). The earlier studies included in Table 5 were all carried out in largely rural locations, and the incinerator inputs were therefore against a much smaller background concentration than in the present study, where the background concentration reflects the historical contamination in a city with a long legacy of industrial activity.

4. Conclusions

In an urban environment, especially one with a history of industrialisation like that of Newcastle upon Tyne, it will always be difficult to isolate the influence of a single source of contamination against the backdrop of elevated concentrations of metals arising from a large number of possible sources. This was the first study carried out in an urban environment since that of Hutton et al. (1988) in London. They reported results for cadmium and lead only, while we obtained data for a wider range of metals and for arsenic, and also used some
complementary methodologies. However, like them, we have to conclude that any effect that the incinerator has had on the soils of the surrounding area was not detectable.

What this study has clearly shown is that the pattern of concentrations, for most of the metals and for arsenic, was characterized by a number of seriously contaminated areas (hotspots) against a generally elevated background concentration. It is likely that this picture will be typical of many industrial cities. A detailed investigation of the land use history can help to explain the source(s) of contamination in many of the hotspots. While this study has highlighted the overall situation, it is the responsibility of the local authorities to undertake further work to assess the risk associated with particular areas of contamination. In this they will be guided by the outputs from the CLEA model. Nevertheless metal contamination of soils in urban areas provides considerable challenges to policy makers and local authorities who need to develop brownfield sites for housing and continue to promote allotment gardens. Finally the work also highlights the need for further research into valid methods to assess both the human and ecosystem risks associated with urban contaminated soils.

**Acknowledgments**

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References


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Pless-Mulloli T, Paepke O and Schilling B. 2002. PCDD/PCDF and heavy metal contamination at Walker Road allotment, Newcastle upon Tyne. University of Newcastle, Newcastle upon Tyne, UK.


Table 1. Soil arsenic and metal concentrations (mg kg\(^{-1}\)) across the study area (n = 163)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>SGV-Res(^1)</th>
<th>SGV -Ind(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>20</td>
<td>15</td>
<td>5</td>
<td>279</td>
<td>20 (52)</td>
<td>500 (0)</td>
</tr>
<tr>
<td>Cd</td>
<td>0.65</td>
<td>0.28</td>
<td>0.01</td>
<td>6.95</td>
<td>1(^a) (36)</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>55</td>
<td>51</td>
<td>23</td>
<td>230</td>
<td>130 (3)</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>233</td>
<td>77</td>
<td>20</td>
<td>12 107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>350</td>
<td>233</td>
<td>40</td>
<td>4 134</td>
<td>450 (27)</td>
<td>750 (13)</td>
</tr>
<tr>
<td>Hg</td>
<td>0.50</td>
<td>0.32</td>
<td>0.03</td>
<td>4.99</td>
<td>8 (0)</td>
<td>480 (0)</td>
</tr>
<tr>
<td>Ni</td>
<td>30</td>
<td>26</td>
<td>11</td>
<td>165</td>
<td>50 (9)</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>419</td>
<td>274</td>
<td>75</td>
<td>4 625</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)CLEA soil guideline value (SGV) for residential areas and allotments (Environment Agency, 2002b), with number of samples exceeding the value in brackets

\(^2\)CLEA soil guideline value (SGV) for industrial areas (Environment Agency, 2002b), with number of samples exceeding the value in brackets

\(^a\)SGV for samples at pH 6

\(^b\)no SGVs available
Table 2. Mean (and median) arsenic and metal concentrations (mg kg\(^{-1}\)) by sector

<table>
<thead>
<tr>
<th></th>
<th>NE  ((n = 61))</th>
<th>NW ((n = 41))</th>
<th>SE  ((n = 42))</th>
<th>SW  ((n = 19))</th>
<th>Overall ((n = 163))</th>
</tr>
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<tbody>
<tr>
<td>As</td>
<td>16 (15)</td>
<td>20 (12)</td>
<td>19 (15)</td>
<td>37 (22)</td>
<td>20 (15)</td>
</tr>
<tr>
<td>Cd</td>
<td>0.33 (0.22)</td>
<td>0.57 (0.24)</td>
<td>1.03 (1.01)</td>
<td>1.00 (0.20)</td>
<td>0.65 (0.28)</td>
</tr>
<tr>
<td>Cr</td>
<td>45 (44)</td>
<td>52 (50)</td>
<td>68 (61)</td>
<td>66 (60)</td>
<td>55 (51)</td>
</tr>
<tr>
<td>Cu</td>
<td>77 (75)</td>
<td>120 (67)</td>
<td>239 (96)</td>
<td>960 (112)</td>
<td>233 (77)</td>
</tr>
<tr>
<td>Pb</td>
<td>230 (204)</td>
<td>312 (207)</td>
<td>443 (267)</td>
<td>615 (273)</td>
<td>350 (233)</td>
</tr>
<tr>
<td>Hg</td>
<td>0.41 (0.35)</td>
<td>0.48 (0.24)</td>
<td>0.41 (0.33)</td>
<td>1.08 (0.40)</td>
<td>0.50 (0.32)</td>
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<tr>
<td>Ni</td>
<td>24 (24)</td>
<td>31 (22)</td>
<td>31 (30)</td>
<td>41 (28)</td>
<td>30 (26)</td>
</tr>
<tr>
<td>Zn</td>
<td>280 (254)</td>
<td>446 (285)</td>
<td>395 (314)</td>
<td>864 (274)</td>
<td>419 (274)</td>
</tr>
</tbody>
</table>
Table 3. Mean concentrations (mg kg\(^{-1}\)) of arsenic and metals for the sampled soils in the study area compared to values in the underlying geological material and to mean background values (or ranges) for soils in England and Wales

<table>
<thead>
<tr>
<th>Soil</th>
<th>Geological material(^1)</th>
<th>Soil(^2)</th>
<th>Soil(^3)</th>
<th>Soil(^4)</th>
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<tbody>
<tr>
<td>As</td>
<td>20</td>
<td>14-15</td>
<td>11</td>
<td>(5.5-8.8)</td>
</tr>
<tr>
<td>Cd</td>
<td>0.65</td>
<td>1.0-1.2</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Cr</td>
<td>55</td>
<td>100-150</td>
<td>41</td>
<td>42</td>
</tr>
<tr>
<td>Cu</td>
<td>233</td>
<td>20-30</td>
<td>23</td>
<td>19</td>
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<tr>
<td>Pb</td>
<td>350</td>
<td>70</td>
<td>74</td>
<td>40</td>
</tr>
<tr>
<td>Hg</td>
<td>0.50</td>
<td></td>
<td></td>
<td>0.09</td>
</tr>
<tr>
<td>Ni</td>
<td>30</td>
<td>50-60</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Zn</td>
<td>419</td>
<td>200</td>
<td>97</td>
<td>78</td>
</tr>
</tbody>
</table>

\(^1\)British Geological Survey (1993)

\(^2\)McGrath & Loveland (1992)

\(^3\)Archer & Hodgson (1987)

\(^4\)Abbott et al. (1997)
Table 4. Mean concentrations (mg kg\textsuperscript{-1}) of arsenic and metals for the sampled soils in the study area compared to the mean values (and/or ranges) in soils sampled in other studies in the Newcastle area

<table>
<thead>
<tr>
<th></th>
<th>This study</th>
<th>Walker Rd Allotment\textsuperscript{1}</th>
<th>Allotments with ash\textsuperscript{2}</th>
<th>Wallsend Burn\textsuperscript{3}</th>
<th>Ouse Burn\textsuperscript{4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>20</td>
<td>47</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>0.65</td>
<td>(1.1–2.7)</td>
<td>(0.3–23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>55</td>
<td>47 (27-96)</td>
<td>39 (20-82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>233</td>
<td>460 (165-2650)</td>
<td>92 (20-325)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>350</td>
<td>975</td>
<td>484</td>
<td>129</td>
<td>167</td>
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<tr>
<td>Hg</td>
<td>0.50</td>
<td>(0.6-1.9)</td>
<td>(0.1-2.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>30</td>
<td>52 (36-114)</td>
<td>34 (20-77)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>419</td>
<td>(460-2430)</td>
<td>(115-971)</td>
<td>282</td>
<td></td>
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</tbody>
</table>

\textsuperscript{1}Pless-Mulloli et al. (2002)
\textsuperscript{2}Pless-Mulloli et al. (2000)
\textsuperscript{3}Mellor (2001)
\textsuperscript{4}Mellor & Bevan (1999)
Table 5. Mean concentrations (mg kg\(^{-1}\)) of arsenic and metals for the sampled soils in the study area compared to the mean values (or range) in soils sampled in other studies in the vicinity of incinerators.

<table>
<thead>
<tr>
<th></th>
<th>This study</th>
<th>Hampshire(^1)</th>
<th>Scotland(^2)</th>
<th>Spain(^3)</th>
<th>Spain(^4)</th>
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</thead>
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<td>As</td>
<td>20</td>
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<td>5</td>
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<td>Cd</td>
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<td>0.7</td>
<td>0.09</td>
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<td>0.2</td>
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<tr>
<td>Cr</td>
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<td>30</td>
<td>18</td>
<td>13</td>
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<tr>
<td>Cu</td>
<td>233</td>
<td></td>
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<td></td>
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<tr>
<td>Pb</td>
<td>350</td>
<td>(16-8300)</td>
<td>42</td>
<td>63</td>
<td>52</td>
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<tr>
<td>Hg</td>
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<td>(0.1-2.8)</td>
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<td>0.06</td>
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<td>(4-87)</td>
<td>15</td>
<td>10</td>
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<tr>
<td>Zn</td>
<td>419</td>
<td></td>
<td>103</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Abbott et al. (1997)
\(^2\)Collett et al. (1998)
\(^3\)Meneses et al. (1999)
\(^4\)Llobet et al. (2002)
Figure legends

**Fig. 1.** Sampling frame and distribution of sampling sites

**Fig. 2.** Soil lead concentrations (mg kg$^{-1}$) by distance band and sector

**Fig. 3.** Soil chromium concentrations (mg kg$^{-1}$) by distance band and sector
Fig. 1. Sampling frame and distribution of sampling sites
mean values in NW, SE, NE sectors; single readings in SW sector

CLEA soil guideline value for residential areas with and without plant uptake and allotments: 450 mg kg\(^{-1}\)

CLEA soil guideline value for commercial & industrial areas: 750 mg kg\(^{-1}\)

Fig. 2. Soil lead concentrations (mg kg\(^{-1}\)) by distance band and sector
mean values in NW, SE, NE sectors; single readings in SW sector

CLEA soil guideline value: 130 mg kg$^{-1}$

**Fig. 3.** Soil chromium concentrations (mg kg$^{-1}$) by distance band and sector