Contamination of allotment soil with lead: managing potential risks to health
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Abstract

Background In the context of contaminated land, assessing risk involves identifying a source, a pathway and a receptor. We describe how this approach worked in practice following the discovery of high lead levels in the soil of an allotment site in a London borough.

Methods Soil and produce analyses were undertaken. A worst-case scenario was constructed to estimate the maximum potential lead intake by consumers. A questionnaire survey was undertaken of individuals who either worked on the allotment or ate significant amounts of produce grown on it. They were also offered blood lead tests.

Results High lead levels were found in soil and produce. The worst-case assessment showed that the estimated lead intake by a hypothetical consumer of allotment produce exceeded the provisional tolerable weekly intake almost 10-fold. Further tests on produce indicated that soil contamination had contributed to the high lead levels. The questionnaire survey did not reveal any chronic illness related to lead exposure. Of the five tested, none had raised blood lead levels.

Conclusions A decision was made to remediate the site. Pending this, we advised the allotment holders not to cultivate the land or eat any produce grown on it as we could not be sure that preparation of the produce before consumption would remove all adherent lead-contaminated soil, and continued cultivation could also expose them to lead in the soil dust.

Keywords: lead, allotments, risk assessment, contaminated land.

Introduction

Government policy on contaminated land is based on a ‘suitable for use’ approach to the control and treatment of existing contamination. This approach requires action where the contamination poses unacceptable actual or potential risks to health and the environment; and there are appropriate and cost-effective means available to do so taking into account the actual or intended use of the site.\(^1,2\) We describe how this policy worked in practice following the discovery of high levels of lead in the soil of an allotment site in an inner London borough.

The lead was found during a rolling programme of testing allotments using the ICRCL (Interdepartmental Committee on the Redevelopment of Contaminated Land) recommended suite of tests\(^3\) that was commissioned by the Local Authority in 1995. This programme of testing was undertaken following the chance discovery of mercury at another allotment site in the borough.

The allotment site is a statutory site,\(^4\) measuring approximately half an acre in size. It is split into 10 plots and at the time of the investigation, nine of the plots were leased to seven plotholders and being cultivated. Ordnance Survey maps in a local museum show that the site has been allotments since at least 1912.

A multidisciplinary team was set up to investigate the problem with representation from the Local Authority (LA), the Health Authority (HA) Public Health Department, the Chemical Incident Response Service at Guy’s & St Thomas’ Hospital Trust (CIRS) and the Ministry of Agriculture, Fisheries and Food (MAFF).

Health effects of lead

Lead enters the body by two main routes: inhalation and ingestion. Regardless of how lead enters the body, most of it is stored in bone.\(^5,6\) It is not broken down into other products, and so tends to accumulate over time. Two groups particularly at risk are children and pregnant women; studies have shown that exposure of the latter to high levels of lead may cause pre-term delivery, smaller babies and reduced growth.\(^7\) There is also an inverse relationship between body lead burden and child IQ.\(^8\)

Acute clinical effects of lead toxicity include anorexia, vomiting, fatigue and depression. Chronic exposure may cause various symptoms including a reduction in IQ, neuromuscular dysfunction, gastrointestinal disturbances, and renal failure.\(^5\)

Blood lead levels are used as a measure of body burden and absorbed (internal) doses of lead. The relationship between blood lead and total lead intake is curvilinear across a broad range of blood lead values.\(^9\)
Methods

Quantitative risk assessment

In the context of contaminated land, assessing the risk\(^1\) involves identifying a source, a pathway and a receptor, which are all interrelated. That is, an identified pathway should be capable of exposing a specified receptor, in this instance humans, to a specified contaminant that has the potential to harm health. If all three elements are not identifiable, then the land is not considered to be contaminated.

Identification of source

Soil sampling and analysis

Initial sampling was carried out in August and September 1997. Five samples were taken from five plots from hand-dug pits at a maximum depth of 0.3 m. Samples were immediately placed in plastic containers before being sent to the laboratory. Once high levels of soil lead were discovered, further samples were taken in March 1998 at three different depths (surface, 0.2 m, 0.8 m) and, at random, from seven plots across the site (Table 1). The soil samples were milled, digested in aqua regia and analysed by spectrophotometry in a laboratory that had NAMAS (National Accreditation of Measurement And Sampling) accreditation (now replaced by UKAS – United Kingdom Accreditation Service).

Identification of the pathway

Produce analyses

Produce samples were taken at the same time as the soil samples. Two vegetables – one leaf and one tuber – were sampled from five of the plots. The lead content of the produce was tested at an accredited laboratory. Fibrous roots and obviously non-edible parts were removed and discarded. No peeling or other selective sub-sampling was carried out. The produce samples were thoroughly washed under running deionized water to remove all visible traces of soil. Samples were drained and blotted dry with clean tissue paper before being oven-dried at 100°C, milled and digested with aqua regia before analysis by spectrophotometry.

Assessment of soil contamination of produce

To test the contribution of soil lead contamination to the levels of lead detected in the produce, MAFF advised that further produce be tested for titanium at the same time as lead. Titanium is present in the soil but its uptake by plants is effectively nil. Therefore, high levels of titanium in produce are indicative of soil contamination. Three types of produce that were still available, fresh rhubarb, leeks and stored potatoes, were sent for this further analysis.

Assessing harm to the receptor

Worst-case scenario

MAFF estimated worse-case potential intakes of lead by consumers of allotment-grown vegetables taking the analytical data at face value and using data, derived from the UK National Diet and Nutritional Survey,\(^{10,11}\) on high-level (97.5th percentile) rates of consumption of the vegetables. MAFF also based the calculations on a provisional tolerable weekly intake (PTWI) of 0.25 mg/kg body weight per week.\(^{12}\)

Questionnaire survey

All seven allotment holders were sent letters and questionnaires, which asked for information about the type of produce grown and amount consumed, as well as any chronic ill health suffered. The data were analysed using Epi Info.\(^13\) Additional appropriately tailored questionnaires were also sent to the allotment holders to forward to any others who regularly worked on the allotment or ate produce from it.

Blood tests

Blood tests for lead were offered to all allotment holders and to others regularly working on or eating produce from the allotments. The blood was analysed at accredited laboratories.

Results

Identification of source

A possible source of the lead on the site was thought to be a joinery workshop that had existed on the site and burned windows and frames containing lead-based paint and putty.

Soil analysis

The initial soil test results when high lead levels were found ranged from 1110 to 4440 mg/kg dry weight. Table 1 shows the results of the further detailed soil analysis. Lead levels were elevated at all depths of soil tested, compared with the ICRCL trigger threshold value.\(^3\)

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Table 1 Allotment soil analysis (March 1998)

<table>
<thead>
<tr>
<th>Plot* samples</th>
<th>Depth taken (m)</th>
<th>Lead in soil (mg/kg dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>0.8</td>
<td>513</td>
</tr>
<tr>
<td>1b</td>
<td>0.2</td>
<td>615</td>
</tr>
<tr>
<td>Junction of 3 and 4</td>
<td>surface</td>
<td>2910</td>
</tr>
<tr>
<td>5</td>
<td>0.2</td>
<td>805</td>
</tr>
<tr>
<td>6a</td>
<td>0.2</td>
<td>935</td>
</tr>
<tr>
<td>6b</td>
<td>surface</td>
<td>1450</td>
</tr>
<tr>
<td>7a</td>
<td>surface</td>
<td>1540</td>
</tr>
<tr>
<td>7b</td>
<td>0.8</td>
<td>1220</td>
</tr>
<tr>
<td>10a</td>
<td>surface</td>
<td>998</td>
</tr>
<tr>
<td>10b</td>
<td>0.2</td>
<td>939</td>
</tr>
<tr>
<td>10c</td>
<td>0.8</td>
<td>928</td>
</tr>
</tbody>
</table>

*The numbering refers to the different plots.
†Comparison values: ICRCL trigger threshold value 500 mg/kg dry weight.
produce was high, exceeding the PTWI (0.25 mg/kg body-weight per week) almost 10-fold. At this level of regular intake, chronic accumulation of lead in the body may occur, resulting in toxic effects. However, it is likely that the worst-case scenario overestimated the actual dietary exposures to lead from produce grown at the site.

**Identification of the pathway**

**Produce analysis**

The produce analysis results are shown in Table 2. The Lead in Food Regulations apply solely to produce for sale and their recommended level is used only as a guide for allotment produce. The lead concentrations reported for the vegetables, especially the lettuce, are much higher than those seen in a MAFF survey of lead in vegetables grown in urban soils.14

**Assessment of soil contamination of produce**

Table 3 shows that the raised lead level in the leeks and, to a lesser extent, the potatoes is associated with raised titanium levels indicating soil contamination of the produce analysed. The rhubarb titanium concentration is very low, indicating that the lead level, which is within the normal range, is more likely to reflect actual uptake by the plant. The rhubarb lead concentration of 0.14 mg/kg together with the soil lead concentrate found at this plot (2010 mg/kg dry weight) would give an uptake of 0.007% (fresh weight produce:dry weight soil). This value is low and within the normal range.

**Assessing harm to the receptor**

**Worst-case scenario**

The estimated intake by a hypothetical consumer of allotment produce was high, exceeding the PTWI (0.25 mg/kg body-weight per week) almost 10-fold. At this level of regular intake, chronic accumulation of lead in the body may occur, resulting in toxic effects. However, it is likely that the worst-case scenario overestimated the actual dietary exposures to lead from produce grown at the site.

**Questionnaire analysis**

All seven allotment holders, and 10 others who ate allotment produce or worked on the allotment regularly, returned completed questionnaires. A total of 17 questionnaires were analysed.

The age of the respondents ranged from 14 to 90 years (from 45 to 86 years for allotment holders). The allotment sites had been rented for periods ranging from 6 months to 20 years (median 6 years). For most respondents, allotment produce accounted for about 25 per cent of their total diet all year round. None of the respondents said they had suffered from a chronic illness since working on or eating produce from the allotments.

**Blood lead levels**

Blood tests were carried out on a total of five persons (four allotment holders and one other). Their lead levels were within the normal range (Table 4).

**Outcome of investigations**

MAFF advised that, if the worst-case estimate was accepted at face value, measures should be taken to reduce or eliminate the consumption of produce grown on the site. MAFF also advised that further investigations would be needed, to determine the extent to which adhering soil contributed to the lead concentrations in vegetables from the site and whether these concentrations could be reduced to an acceptable level by thorough washing and peeling. However, it was not possible to conduct these investigations because of concerns about exposing the allotment holders to an unquantified potential risk from the continued use of the site, which would have been necessary to obtain further produce samples for analysis. The allotment holders were advised not to cultivate the land until

### Table 2 Plant tissue analysis*

<table>
<thead>
<tr>
<th>Plot/produce</th>
<th>Lead in leaf tissue</th>
<th>Lead in tuber tissue</th>
<th>Lead in Food Regulations 1979†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/cabbage</td>
<td>0.18</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1/carrot</td>
<td>2.36</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>5/cabbage</td>
<td>2.88</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>5/parsnip</td>
<td>26.2</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>7/lettuce</td>
<td>3.58</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>7/beetroot</td>
<td>1.19</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>8/potato</td>
<td>1.72</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

*Values mg/kg wet weight.
†The Lead in Food Regulations 1979 (S.I. 1979 No. 1254) as amended by the Lead in Food (Amendment) Regulations 1985 (S.I. 1985 No. 912).

### Table 3 Analysis of lead and titanium in selected produce*

<table>
<thead>
<tr>
<th>Produce</th>
<th>Concentration of lead in tissue†</th>
<th>Concentration of titanium in tissue†</th>
<th>Lead in Food Regulations 1979†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhubarb</td>
<td>0.14</td>
<td>&lt;0.01</td>
<td>1.0</td>
</tr>
<tr>
<td>Leeks</td>
<td>4.63</td>
<td>4.57</td>
<td>1.0</td>
</tr>
<tr>
<td>Potatoes</td>
<td>0.45</td>
<td>0.10</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Values mg/kg wet weight.
†Leaf tissue of rhubarb and leeks; tubers of potatoes.
†The Lead in Food Regulations 1979 (S.I. 1979 No. 1254) as amended by the Lead in Food (Amendment) Regulations 1985 (S.I. 1985 No. 912).

### Table 4 Blood lead levels

<table>
<thead>
<tr>
<th>Patient</th>
<th>Lead level in whole blood (reference range)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.12 µmol/l (&lt;0.5)</td>
</tr>
<tr>
<td>2</td>
<td>0.45 µmol/l (&lt;0.5)</td>
</tr>
<tr>
<td>3</td>
<td>0.21 µmol/l (&lt;0.5)</td>
</tr>
<tr>
<td>4</td>
<td>100 µg/l (≤100)</td>
</tr>
<tr>
<td>5</td>
<td>20 µg/l (≤100)</td>
</tr>
</tbody>
</table>

*Patients 1, 2 and 3 had their blood analysed at Southampton SupraRegional Assay Service Trace Element Unit; patients 4 and 5 at the Medical Toxicology Laboratory, Guy’s and St Thomas’ Hospital Trust.
it had been remediated and to discard any remaining produce, either fresh or stored, from the allotment.

**Discussion**

**Generic guidelines in risk assessment**

Risk assessments can be carried out by various different methods, e.g. with reference to generic guideline values, as in this instance, or by a site-specific estimation of risks derived from detailed consideration of the particular characteristics of the sources, pathways and targets of the site.\(^\text{15}\)

Generic guidelines have advantages in terms of ease of use, but may be based on assumptions not appropriate for a particular situation.\(^\text{13} 15\) Currently, the decision to remediate or not is based on trigger levels contained within generic guidance notes prepared by government advisory bodies, e.g. ICRCL guidelines. There are disadvantages to using such standard, fixed levels for all sites. These include the fact that apart from having no statutory power, they are not specifically designed for sole use in remediation decisions.\(^\text{16}\)

The ICRCL guidelines are applicable only to land being redeveloped, not to sites already in use.\(^\text{15}\) They are also not site-specific and are incomplete in terms of contaminants listed.

A site-specific assessment involves the exposure pathway to a potential receptor being assessed based on the site-specific conditions, the end-use options and the toxicity of individual chemicals that pose the most significant concern. The risk posed to selected receptors is then determined and the decision to remediate is defined in terms of an acceptable risk level tailored to the end-use of the site, i.e. not multifunctional.

The advantages of this approach\(^\text{15}\) are that the levels defined are sensitive to human health and environmental impact, the levels are less sensitive to statutory change, and the approach provides a comprehensive assessment of factors of concern identified in the site investigation.

**Interpreting soil and produce results**

Lead levels in the allotment soil were at the upper end of those found in a survey of soils in the United Kingdom, which were in the range 20–131 mg/kg d.w. (dry weight, 10th and 90th percentile) for typical UK soils\(^\text{17}\) and 27–1676 mg/kg d.w. (geometric mean 266) for urban UK soils.\(^\text{14}\)

Because of the high cost of a large number of samples being analysed, initially a limited number of samples were taken. When high lead levels were found in these samples, further soil samples were taken at three different depths and randomly spread across the entire site. However, no particular sampling pattern was observed, such as the herringbone pattern, which maximizes the ability to cover areas difficult to reach for sampling but that might have the highest concentrations of lead.\(^\text{18}\) Therefore, there could have been even higher soil lead levels than those recorded.

The lead levels in the produce were much higher than expected based on what is known about the uptake of lead from soil by vegetables. Lead uptake by plants is known to be low,\(^\text{10,14,19}\) except at acidic pH. The one recorded pH at the allotment site was 7.7 and, although it may not have been representative of the pH of the rest of the allotment, at this level one would not expect uptake of lead to occur to a significant extent.\(^\text{9,14}\) This suggested that the presence of adhering soil may have resulted in the elevated lead concentrations reported in the produce. Where lead contamination is not uniformly distributed in the soil, small soil particles with very high lead concentrations may artificially raise the level of lead in the produce. The selection of tissue analysed, e.g. inner versus outer leaves or, as in our case, the entire leaf tissue, could also influence this result. In fact, the lead concentrations at the allotment site were sufficiently high that only a very small quantity of adhering soil could significantly elevate the produce lead concentration.

The titanium testing supported the view that elevated lead levels in the crops were associated with surface contamination with soil. However, the exact contribution of soil contamination of produce to the raised lead levels was difficult to ascertain. The titanium testing was performed only on a limited range of produce that was available at the time. Therefore, we could not assess whether the high lead levels in all the different types of produce analysed initially were due to contamination with soil lead. Ideally, to assess the contribution of soil contamination to the dietary intake of lead, further produce needed to be grown on the allotment site for more detailed analysis. This was not undertaken because it would have exposed allotment holders to an unquantified potential risk from the continued use of the site.

**Bioavailability of lead**

Speciation of lead should be considered in a quantitative risk assessment. The form in which lead is present determines its solubility, migration and bioavailability. For example, most lead in soils and dusts is biologically inert and it is only the more soluble compounds that present a potential hazard to plants, animals and man.\(^\text{20}\)

The relationship between the species of lead in soil and plants and how this affects human exposure and uptake is not known for certain. It is also dependent on a number of other factors such as climatic conditions,\(^\text{20,21}\) stomach acidity and intake of certain foods, e.g. those rich in calcium.\(^\text{7,10,22}\)

Currently, there is no broadly accepted chemical method for analysing environmental materials to quantify biologically active lead. This means that bioavailability will continue to be difficult to assess and include as part of a risk assessment.\(^\text{20}\)

As the majority of environmental lead is present in inorganic forms, in this investigation the lead was assumed to be inorganic.

**Assessing harm to allotment holders**

The worst-case scenario probably greatly overestimated the actual dietary exposure to lead from foods grown on the
allotment. It was inherently pessimistic and assumed that the local site provided 100 per cent of the consumption of those foods grown there and that the lead concentrations in food were as reported. MAFF’s routine advice to consumers is that produce should always be thoroughly washed and peeled, as appropriate, before consumption. Such preparation would be expected to reduce both soil contamination and lead content of vegetables (e.g. root vegetables, which concentrate lead in their skins). This means that the concentrations in the produce as consumed were likely to be lower than those reported.

Despite some of the allotment holders working on the land for up to 20 years and a significant proportion of their diet coming from the allotment, none of them indicated that they were suffering any ill health related to lead. In addition, their blood lead levels, which represent the most direct assessment of lead exposure from all sources, were within the normal range. However, in the presence of extremely high soil lead concentrations, as in our case, the removal of adhering soil would need to be extremely efficient to ensure that the lead intake was below that which could represent a risk to consumers. It is debatable how successful the allotment holders would be at achieving this in practice, especially as soil contamination does not necessarily have to be visible to make a significant contribution to the lead content. Faced with continuing high levels of lead, it would be difficult to exclude a risk to health at some point in the future.

Conclusions

Ultimately, the most important aspect of the risk assessment was the high soil lead levels on which the decision to remediate the land was based. This raises the question of whether a detailed risk assessment is always necessary when extremely high levels of lead are found in the soil. Despite remediation being approved by the LA, it has still not been carried out because the cost is prohibitive. At present, the authority is waiting to see if funding approval is granted to a local university to use the allotment site as an experimental area for remediation.

The identification of areas of contaminated land is becoming more common as techniques for analysis and management of likely contaminants improve, and in the face of increasing public pressure for a cleaner environment. Action now to improve both the HA and LA pool of resources and information will enable us to manage future incidents more effectively and efficiently together. At present, this is an area that is not dealt with on a regular basis by public health departments, and a standard approach to the management of such incidents would be helpful.

Acknowledgements

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