Chapter 1

Contaminated Land and the Link to Human Health

Learning Objectives

- To appreciate the environmental impact that people have had on the land on which we live.
- To be aware of the statutory responsibilities that local authorities in England have as a result of the Environmental Protection Act 1990: Part IIA.
- To appreciate the link between contaminated land and human health.
- To be aware of the UK Soil Guidelines Values for metals and persistent organic pollutants.
- To define the different land uses that are linked to the UK Soil Guidelines Values.
- To be able to define the following terms: exposure, intake dose, uptake dose and bioavailability.
- To be able to calculate the mean-test value for an environmental pollutant.
- To be able to calculate the maximum-test value for an environmental pollutant.

1.1 Introduction

The land on which we live is a precious resource that needs to be protected and conserved. However, the utilization of the land by humans has resulted in its contamination. When you travel around the country, you become aware of

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the issues associated with past industrial activity, for example, the remnants of former tin mines in Cornwall, derelict mine workings in Yorkshire and former mills in Lancashire, as well as the clearing of former industrial sites to build new houses and offices. All households and commercial activities generate waste that is removed by waste-disposal engineers from our bins.

SAQ 1.1

Where does the waste from your household end up?

In England, the Contaminated Land Regulations (Environmental Protection Act 1990: Part IIA) came into force in April 2000. These regulations require local authorities in England to identify sites which fall under the definition of ‘contaminated land’ and provide suitable remediation options that agree with the ‘suitable-for-use’ approach. The statutory responsibilities on local authorities include the following:

- To inspect their areas to identify contaminated land.
- To prepare and serve notifications of contaminated land.
- To establish whether sites should be designated as ‘special sites’ and thus become the responsibility of the Environment Agency.
- To serve remediation notices where necessary.
- To undertake assessment of the best practicable remediation option and test for ‘reasonableness’.
- To consult other parties, including the Environment Agency.
- To compile and maintain registers of contaminated land.

The inspection of areas of potential contaminated land by local authorities is an important first step in this process. As well as inspecting the land, it is necessary to identify whether it has a significant pollutant linkage between a source (i.e. the contaminant), a pathway (e.g. ingestion) and a receptor (e.g. a human being). This present book is concerned with these linkages and the approaches available to establish whether pollutants are bioavailable.

1.2 Soil Guideline Values

In the UK, Soil Guideline Values (SGVs) have been and are being developed for a range of metals/metalloids and organic contaminants in order to assess the risk to humans. In selecting the potential contaminants to be explored, two criteria have been used [1]:

(1) Contaminants should be commonly found on many sites and at concentrations likely to cause harm.

(2) Contaminants that show a potential risk to humans and/or have the potential to cause issues associated with natural waters, ecosystems or the integrities of buildings.

The lists of potential inorganic and organic contaminants identified for the assessment of industrial land in the UK (and their receptors) are shown in Table 1.1 and 1.2, respectively. Soil Guideline Values represent 'intervention values', i.e. an indicator that a soil concentration above the stated level might provide an

Table 1.1 Inorganic contaminants and their receptors [1]

Contaminant	Receptors			
	Humans	Water	Vegetation and ecosystem	Construction materials
Metals				
Barium		✓		
Beryllium	✓	✓	✓	
Cadmium	✓	✓	✓	
Chromium	✓	✓		
Copper		✓	✓	
Lead	✓	✓	✓	
Mercury	✓	✓	✓	
Nickel	✓	✓	✓	
Vanadium	✓	✓		
Zinc			✓	
'Semi-metals' and non-metals				
Arsenic	✓	✓		
Boron		✓	✓	
Selenium	✓	✓	✓	
Sulfur	✓		✓	✓
Inorganic chemicals				
Cyanide (complex)	✓	✓	✓	✓
Cyanide (free)[a]	✓	✓	✓	
Nitrate		✓		
Sulfate		✓	✓	✓
Sulfide		✓	✓	✓
Other				
Asbestos	✓			
pH (acidity/alkalinity)	✓	✓	✓	✓

[a] Free cyanide is broadly equivalent to 'easily liberatable cyanide', which covers compounds that can release hydrogen cyanide at pH 4 and 100°C.

Table 1.2 Organic contaminants and their receptors [1]

Contaminant	Receptors			
	Humans	Water	Vegetation and ecosystem	Construction materials
Acetone	✓	✓		
Oil/fuel hydrocarbons	✓	✓	✓	✓
Aromatic hydrocarbons				
Benzene	✓	✓	✓	✓
Chlorophenols	✓	✓	✓	✓
Ethylbenzene	✓	✓	✓	✓
Phenol	✓	✓	✓	✓
Toluene	✓	✓	✓	✓
o-Xylene	✓	✓	✓	✓
m,*p*-Xylene	✓	✓	✓	✓
Polycyclic aromatic hydrocarbons	✓	✓		
Chlorinated aliphatic hydrocarbons				
Chloroform	✓	✓	✓	
Carbon tetrachloride	✓	✓	✓	✓
Vinyl chloride	✓	✓		
1,2-Dichloroethane	✓	✓	✓	✓
1,1,1-Trichloroethane	✓	✓	✓	✓
Trichloroethene	✓	✓	✓	✓
Tetrachloroethene	✓	✓	✓	✓
Hexachlorobuta-1,3-diene	✓	✓	✓	
Hexachlorocyclohexanes	✓	✓	✓	
Dieldrin	✓	✓	✓	
Chlorinated aromatic hydrocarbons				
Chlorobenzenes	✓	✓	✓	
Chlorotoluenes	✓	✓	✓	
Pentachlorophenol	✓	✓	✓	
Polychlorinated biphenyls	✓	✓	✓	
Dioxins and furans	✓	✓	✓	
Organometallics				
Organolead compounds	✓		✓	
Organotin compounds	✓	✓		

unacceptable risk to humans and that further investigation and/or remediation is required. As well as the numerical values associated with the concentration of the contaminant, limits are indicated for a range of land-uses. The standard land-uses defined are residential, allotments and commercial/industrial. These land-uses are defined as follows [1–11].

1.2.1 Residential

People live in a wide variety of dwellings including, for example, detached, semi-detached and terraced properties, up to two storeys high. This land-use takes into account several different house designs, including buildings based on suspended floors and ground-bearing slabs. It assumes that residents have private gardens and/or access to community open spaces close to the home. Exposure has been estimated with and without a contribution from eating home-grown vegetables, which represents the key difference in potential exposure to contamination between those living in a house with a garden and those living in a house where no private garden area is available.

1.2.2 Allotments

These represent the provision of open space, commonly made by the local authority, for local people to grow fruit and vegetables for their own consumption. Typically, each plot is about one-fortieth of a hectare, with several plots to a site. Although some allotment holders may choose to keep animals, including rabbits, hens and ducks, potential exposure to contaminated meat and eggs has not been considered.

1.2.3 Commercial/Industrial

There are many different kinds of workplace and work-related activities. This land-use assumes that work takes place in a permanent single-storey building, factory or warehouse where employees spend most time indoors involved in office-based or relatively light physical work. This land-use is not designed to consider those sites involving 100% 'hard cover' (such as car parks), where the risks to the site-user are from ingestion or skin contact, because of the implausibility of such exposures arising while the constructed surface remains intact.

Soil Guideline Values, according to the different land-uses, for selected metals are shown in Table 1.3 while those for organic compounds are shown in Table 1.4. It is observed that while the concentrations differ for each metal/organic compound, due to their different toxicities, some common aspects are observed with respect to land-use.

DQ 1.1

Which type of land-use has the highest concentration?

Answer

The highest concentrations are observed for land to be used for commercial/industrial activities.

Table 1.3 Soil Guideline Values according to land-use for selected metals

Standard land-use	Soil Guideline Values ($mg\,kg^{-1}$ dry weight soil)						
	Arsenic[a]	Cadmium[b]	Chromium[c]	Lead[d]	Inorganic mercury[e]	Nickel[f]	Selenium[g]
Residential with plant uptake	20	1–8[h]	130	450	8	50	35
Residential without plant uptake	20	30	200	450	15	75	260
Allotments	20	1–8[h]	130	450	8	50	35
Commercial/ industrial	500	1400	5000	750	480	5000	5000

[a] Data taken from DEFRA/EA [2].
[b] Data taken from DEFRA/EA [3].
[c] Data taken from DEFRA/EA [4].
[d] Data taken from DEFRA/EA [5].
[e] Data taken from DEFRA/EA [6].
[f] Data taken from DEFRA/EA [7].
[g] Data taken from DEFRA/EA [8].
[h] Values alter with respect to pH: 1, 2 and 8 $mg\,kg^{-1}$ dry weight soil for pH 6, 7 and 8, respectively.

Table 1.4 Soil Guideline Values according to land-use for selected organic compounds[a]

Standard land-use	Soil Guideline Values ($mg\,kg^{-1}$ dry weight soil)								
	Ethylbenzene[b]			Phenol[c]			Toluene[d]		
	1% SOM	2.5% SOM	5% SOM	1% SOM	2.5% SOM	5% SOM	1% SOM	2.5% SOM	5% SOM
Residential with plant uptake	9	21	41	78	150	280	3	7	14
Residential without plant uptake	16	41	80	21900	34400	37300	3	8	15
Allotments	18	43	85	80	155	280	31	73	14
Commercial/ industrial	48 000	48 000	48 000	21 900	43 000	78 100	150	350	680

[a] SOM, soil organic matter.
[b] Data taken from DEFRA/EA [10].
[c] Data taken from DEFRA/EA [11].
[d] Data taken from DEFRA/EA [9].

As can be seen above from the definition of commercial/industrial land, the risk to humans is minimal. This is in contrast to other land-uses, i.e. allotments and residential, where the SGVs are significantly lower.

DQ 1.2

What is the consequence to humans of low SGVs?

Answer

In these situations, the risk to humans is greatest and therefore the soil requirement in terms of metal concentration is lower.

It is also noted that cadmium (Table 1.3) has SGVs for 'residential-with-plant-uptake' sites and allotments which are pH-dependent. In addition, all data for organic compounds (Table 1.4) are soil organic matter-dependent.

1.3 Risk to Humans

The risk to humans from exposure to environmental contaminants is a major concern of regulatory agencies in countries worldwide. In this context, environmental contaminants relates to organic compounds, metals, metalloids, inorganic chemicals and others (including asbestos). Exposure to these environmental contaminants can result from a variety of pathways.

SAQ 1.2

Which types of *direct* exposure pathways can you think of?

DQ 1.3

Which types of *indirect* exposure pathways can you think of?

Answer

Indirect exposure can occur via pathways through the food chain, including contaminant uptake by plants followed by consumption by animals or humans. In the case of the former, exposure can continue through the food chain for the majority of humans who pursue an omnivorous or carnivorous diet.

Exposure can be defined as 'the amount of chemical that is available for intake by a target population at a particular site. Exposure is quantified as the concentration of the chemical in the medium (for example, air, water or food) integrated over the duration of exposure. It is expressed in terms of mass of substance per kg of soil, unit volume of air or litre of water (for example, $mg\,kg^{-1}$, $mg\,m^{-3}$ or $mg\,l^{-1}$)' [12]. As chemical exposure to humans occurs externally, this is referred to as the intake dose. The **intake dose** is defined as follows: 'the amount of a chemical entering or contacting the human body at the point of entry (that is, mouth, nose or skin) by ingestion, inhalation or skin contact. Actual intake will be a function of the chemical characteristics and the nature of the target

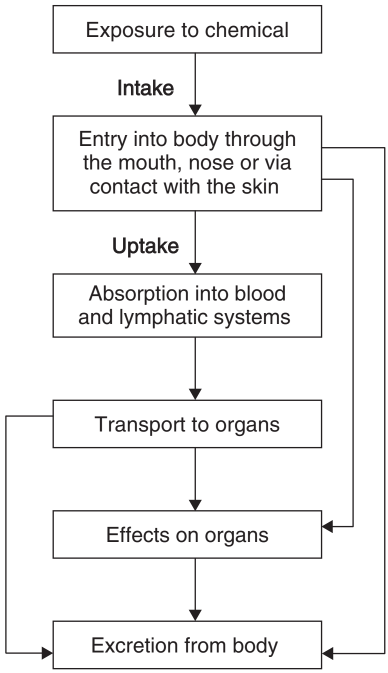

Figure 1.1 Human exposure to chemicals and the possible pathways (modified from DEFRA/EA [12]).

population and their behaviour patterns. Intake dose is expressed in terms of mass of substance per kg of body weight over a period of time (for example, $mg\,kg^{-1}$ $bw\,d^{-1}$)' [12]. However, not all substances that are 'intaken' by the body are absorbed and therefore it is possible to define the **uptake dose** as 'the amount of a contaminant that reaches the circulating blood having been absorbed by the body through the skin, the gastrointestinal system and the pulmonary system, expressed in terms of mass of substance per unit volume of blood (for example, $mg\,l^{-1}$)' [12]. In reality, the uptake dose is normally related to the intake (dose) by the **bioavailability** of the contaminant. Bioavailability is therefore defined as follows: 'the fraction of the chemical that can be absorbed by the body through the gastrointestinal system, the pulmonary system and the skin' [12]. The relationship between exposure, intake and uptake is shown in Figure 1.1.

1.4 An Approach to Assess Contaminated Soils Relative to Soil Guideline Values

The human health risk from a contaminated site can be determined after sampling of the designated area followed by the appropriate analytical technique to determine the level of contamination (see Chapters 2 and 3). Once the level of contamination, from the designated site, has been determined, the determined values can be compared to the appropriate SGVs. A statistical approach to compare values, has been determined [13] based on the **Mean-Value Test**. In order to compare values, the following information is required from the chosen, appropriately sampled, contaminated site:

- arithmetic sample mean
- standard deviation of the mean
- maximum concentration value obtained.

This approach is based on an identification of the 95% confidence limit of the measured (concentration) mean value and to compare the upper 95th percentile value with the SGV using the mean-value test described below.

1.4.1 Mean-Value Test [13]

The sample mean value (x), based on only a few samples, may be a poor estimate of the true (population) mean. Therefore, a 'no-remedial action' decision based on x less than the Soil Guideline Value, G, may not be adequately 'health-protective' when x is computed from only a small number of samples. It is therefore desirable to state with a given confidence (e.g. the 95th percentile) that the population mean is less then the value of G.

The steps involved in the calculation are as follows:

(1) Calculate the arithmetic sample mean, x.

(2) Calculate the (unbiased) sample standard deviation, s.

(3) Select an appropriate t-value from standard tables (Table 1.5 gives the t-values for a 95th percentile confidence limit).

Table 1.5 Single-tailed t-values (95th percentile confidence limits) and their relationships to sample sizes (n) [13]

n	*t*	*n*	*t*	*n*	*t*
—	—	11	1.812	21	1.725
2	6.314	12	1.796	22	1.721
3	2.920	13	1.782	23	1.717
4	2.353	14	1.771	24	1.714
5	2.132	15	1.761	25	1.711
6	2.015	16	1.753	26	1.708
7	1.943	17	1.746	27	1.706
8	1.895	18	1.740	28	1.703
9	1.860	19	1.734	29	1.701
10	1.833	20	1.729	30	1.699

(4) Calculate the upper 95th percentile bound of the sample as:

$$US_{95} = \overline{x} + \frac{ts}{\sqrt{n}}$$

(5) Compare the upper bound value (US_{95}) with the Soil Guideline Value, G.

If the upper bound value (US_{95}) is less than G, then the Mean-Value Test has been passed and the site may be considered not to present a significant possibility of significant harm to human health in the context of the regulations (Environmental Protection Act 1990: Part IIA). Conversely, if the test fails, then it is necessary to consider whether more samples should be taken (as the number of original samples for the test was low) or to make a determination as contaminated land (Environmental Protection Act 1990: Part IIA), taking into account the other requirements of the regime, such as presence of a significant pollutant linkage.

NOTE: Some analytical data sets will include samples determined as below the detection limit of the instrument used. In these cases, and for the purposes of performing the calculation, assign a value equal to the detection limit. For example, if the value reported for Pb is $< 0.5\,\text{mg kg}^{-1}$, a value of $0.5\,\text{mg kg}^{-1}$ should be used for calculation.

DQ 1.4

Carry out the Mean-Value Test [13] for the following ten samples taken from a residential site (without plant uptake) where the level of chromium contamination (mg kg^{-1} dry weight soil) was determined to be as follows:

$x_1 = 69$	$x_2 = 120$	$x_3 = 220$	$x_4 = 376$	$x_5 = 156$
$x_6 = 109$	$x_7 = 205$	$x_8 = 320$	$x_9 = 96$	$x_{10} = 196$

The Soil Guideline Value (G) for chromium is 200 (Table 1.3).

Answer

By using the above data, it is possible to:

(1) Calculate the arithmetic sample mean, $\overline{x}$, as 186.70.

(2) Calculate the (unbiased) sample standard deviation, s, as 99.24.

(3) Obtain the t-value from Table 1.5 for $n = 10$, as $t = 1.833$.

(4) Calculate the upper 95th percentile bound of the sample as:

$$US_{95} = \overline{x} + \frac{ts}{\sqrt{n}}$$

$$US_{95} = 186.70 + [(1.833)(99.24)]/\sqrt{10}$$

$$US_{95} = 244.22$$

(5) Compare the upper bound value (US_{95}) with the Soil Guideline Value, G.

The upper bound value is greater than the Soil Guideline Value of 200 and therefore the data do NOT pass the Mean-Value Test. In these circumstances, two options are possible: take further samples to gain a more representative sampling of the site or take remedial action, if, for example, further sampling is not practicable, or time-scales dictate rapid action.

SAQ 1.3

Carry out the Mean-Value Test for the following data and recommend what, if any, further action is required.

The following twelve samples were taken from a commercial site and the level of arsenic contamination (mg kg^{-1} dry weight soil) was determined to be as follows:

$x_1 = 189$	$x_2 = 520$	$x_3 = 420$	$x_4 = 324$	$x_5 = 356$	$x_6 = 450$
$x_7 = 506$	$x_8 = 410$	$x_9 = 380$	$x_{10} = 389$	$x_{11} = 456$	$x_{12} = 502$

The Soil Guideline Value (G) for arsenic is 500.

1.4.2 Maximum-Value Test [13]

Individual contamination values that exceed the SGVs will always require further investigation, even when the Mean-Value Test has been passed. However, the issue of accepting or rejecting maximum values that exceed the SGVs is not straightforward. The primary goal of health protection needs to be balanced against the fact that sampling of contaminated sites, followed by analytical measurement, can lead to significant variability in the data obtained, particularly at low analyte concentrations. In deciding whether to take additional samples to analyse (as indicated in the example above) it is necessary to consider whether the maximum value in a given data set has come from the sample statistical population or indeed whether it is, in fact, a statistical outlier.

One approach [13] assumes that all data are derived from a normal statistical population. It is argued [13] that it is reasonable to 'log' the measured values as this results in a more-or-less symmetric distribution which approximates to a normal distribution.

In operation, the individual measurements ($x_1, x_2 \ldots x_n$) are 'log-transformed' prior to calculation of the sample mean ($\overline{y}$) and unbiased sample standard deviation (S_y). The Maximum-Value Test parameter (T) is therefore:

$$T = (y_{\text{max}} - \overline{Y})/S_y$$

If the value of T is smaller than some critical value, the maximum value may be accepted (at the particular level of confidence) as a member of the underlying population from which the other measurements were taken. If T is greater than the critical value, the maximum value is treated as an *outlier*, which may indicate a localized area of contamination.

DQ 1.5

Carry out the Maximum-Value Test [13] for the following ten samples taken from a residential site (without plant uptake) where the level of chromium contamination (mg kg^{-1} dry weight soil) was determined to be as shown in Table DQ 1.5 (expressed in concentrations and log concentrations).

Table DQ 1.5 Sample data for the Maximum-Value Test

i	x_i	$y_i = \log x_i$
1	69	1.839
2	120	2.079
3	220	2.342
4	376	2.575
5	156	2.193
6	109	2.037
7	205	2.312
8	320	2.505
9	96	1.982
10	196	2.292

The objective is to decide whether the maximum value, $x_4 = 376$ ($y_{max} = 2.575$), should be treated as an outlier, or whether it is reasonable to be considered as coming from the same underlying population as the other samples.

Answer

By using the above data, it is possible to:

(1) Calculate the arithmetic sample mean of the y-values, as $\overline{y} = 2.216$.

(2) Calculate the (unbiased) standard deviation of the y values, as $s_y = 0.2337$.

Table 1.6 Critical values to test for the presence of outliers [13]

N	5%	10%
4	1.46	1.42
5	1.67	1.60
6	1.82	1.73
7	1.94	1.83
8	2.03	1.91
9	2.11	1.98
10	2.18	2.04
12	2.29	2.13
14	2.37	2.21
16	2.44	2.28
18	2.50	2.33
20	2.56	2.38

(3) Obtain the outlier test statistic as:

$$T = (y_{\max} - \overline{Y})/s_y$$

$$T = (2.575 - 2.216)/0.2337 = 1.54$$

Then, compare this value ($T = 1.54$) with the critical value (T_{crit}) in Table 1.6.

In the context of critical values being used for contaminated soil analysis, the concern is with regard to accepting a value which should be treated as an outlier. As 10% critical values are more stringent, they should be used for health-protection purposes, rather than the 5% values.

Therefore, the maximum value statistic calculated above ($T = 1.54$) is less than the 10% critical value of 2.04. Thus, it is reasonable to conclude that the maximum value is indeed part of the same underlying distribution as the other values.

NOTE: It is worth remembering that passing an outlier test does not prove that a maximum value is not an outlier possibly representing an (undiscovered) area of contamination. It simply indicates that the maximum value is reasonably consistent with belonging to the same underlying distribution as other measurements.

SAQ 1.4

Carry out the Maximum-Value Test for the following data and determine whether the value is an outlier or not [13].

The following twelve samples were taken from a commercial site and the level of arsenic contamination (mg kg^{-1} dry weight soil) was determined to be as shown in Table SAQ 1.4 (expressed in concentrations and log concentrations).

Table SAQ 1.4 Sample data for the Maximum-Value Test

i	x_i	$y_i = \log x_i$
1	189	2.276
2	520	2.716
3	420	2.623
4	324	2.510
5	356	2.551
6	450	2.653
7	506	2.704
8	410	2.613
9	380	2.580
10	389	2.590
11	476	2.678
12	502	2.701

Summary

The link between human health and contaminated land is demonstrated in this chapter, in particular, the regulations placed on local authorities in the UK as a result of the Environmental Protection Act 1990: Part IIA. Examples of Soil Guideline Values (SGVs) are presented, along with their use for defining limits associated with different land-uses, including residential, allotments and commercial/industrial sites. An approach to assess contaminated soils relative to the SGVs is given based on the Mean-Value and Maximum-Value Tests.

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