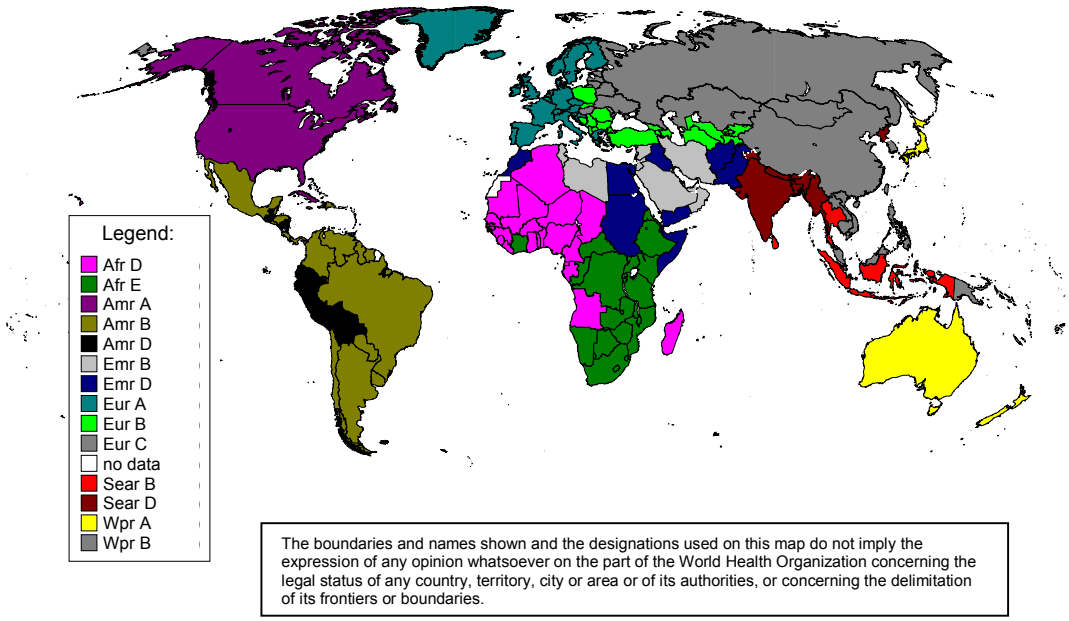
Annex 4 Estimating the global disease burden of environmental lead exposure

The global disease burden for children and adults that results from environmental lead exposure was assessed in 14 regions (Prüss-Üstün et al., 2003). The regions were grouped as shown in Figure A4.1. The countries in each region are given in Annex 1.

Figure A4.1 Regions used to assess the global disease burden



Exposure was assessed by reviewing the literature for studies that measured the distribution of blood lead levels. Only recent studies were considered because of the changes in lead exposure that have occurred since the 1970s, mainly due to lead reduction programmes (e.g. the phasing out of leaded gasoline). If current data were not available for a study, and instead, data prior to the introduction of a lead reduction programme were used, current blood lead levels were estimated by reducing the reported levels by 7.8% for every year that the programme had been implemented. To account for the reduction in exposure from ongoing lead reduction programmes in countries for which there were no data, we extrapolated from known values. For countries with more than one blood lead sample, the samples were first adjusted for lead reduction efforts or missing data, as necessary, and then geometric means were calculated by weighting according to sample size. Regional means were calculated by weighting country means by the size of its urban population. Means for urban and rural populations were estimated separately.

The compiled data are shown in Table A4.1. It was estimated that 120 million people had blood lead levels of 5–10 μg/dl in 2000, and about the same number had levels above 10 μg/dl. Data for all of the children in the samples showed that 97% lived in developing regions; 40% had blood lead levels above 5 μg/dl, and 20% above 10 μg/dl. Less than 10% of the children had levels above 20 μg/dl, but 99% of them lived in developing regions.

Table A4.1 Blood lead levels in children and adults, by region and data source

Region	AfrD[a]	AfrE[a]	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Regional mean blood lead, urban children, (µg/dl)[b]	11.1	9.8	2.2	7.0	9.0	6.8	15.4	3.5	5.8	6.7	7.4	7.4	2.7	6.6
Regional mean blood lead, urban adults, (µg/dl)[b]	11.6	10.4	1.7	8.5	10.8	6.8	15.4	3.7	9.2	6.7	7.4	9.8	2.7	3.6
Standard deviation (µg/dl)	5.6	5.6	2.9	3.9	3.9	3.9	5.6	1.9	3.0	3.0	3.0	5.6	1.9	3.0
Urban population (%)	36	25	77	74	58	67	37	78	62	72	31	26	80	32
Countries for which recent data were available	Nigeria[1]	South Africa[2]	Canada[3], USA[4]	Argentina[5] Brazil[6], Chile[7], Jamaica[8], Mexico[9], Uruguay[10], Venezuela[11]	Ecuador[12], Nicaragua[13], Peru[14]	Saudi Arabia[15]	Egypt[16], Morocco[17], Pakistan[18]	Denmark[19], France[20], Germany[21], Greece[22], Israel[23], Sweden[24]	Poland[25], Turkey[26], Yugoslavia[27]	Hungary[28], Russian Federation[29]	Indonesia[30], Thailand[31]	Bangladesh[32], India[33]	Australia[34], Japan[35], New Zealand[36], Singapore[37]	China[38], Micronesia[39], Philippines[40], Republic of Korea[41]
Children with 5–10 µg/dl blood lead (%)	18.6	19.1	12.4	21.2	23.2	23.3	18.1	22.7	22.7	23.6	21.8	19.2	14.1	21.8
Children with 10–20 µg/dl blood lead (%)	10.0	8.9	4.7	16.3	16.4	15.7	10.1	5.1	13.8	16.3	11.2	8.8	2.9	10.9
Children with blood lead >20 µg/dl (%)	13.9	9.5	1.9	16.7	17.2	11.4	17.2	0.5	8.9	11.9	6.5	8.3	0.3	5.8
Adults with 5–10 µg/dl blood lead (%)	18.5	19.1	9.1	22.1	22.6	23.3	18.1	24.3	22.5	23.6	21.8	19.1	14.1	20.6
Adults with 10–20 µg/dl blood lead (%)	10.0	8.9	3.2	17.2	16.6	15.7	10.1	5.7	16.7	16.3	11.2	9.0	2.1	8.4
Adults with blood lead >20 µg/dl (%)	14.3	9.8	1.1	19.9	20.1	11.4	17.2	0.6	15.5	11.9	6.5	9.7	0.1	2.8

[a] Regional exposure data were combined for these analyses.

[b] High and low urban blood lead means were used in regions where countries were at different stages of phasing out of leaded gasoline; the distribution is therefore a superposition of two or three log-normal distributions, and the mean and standard deviation does not necessarily reflect the distributions; therefore only one mean and standard deviation, as well as the distribution of people in exposure categories 5–10, 10–15 and 15–20 µg/dl are displayed.

Sources of country data: [1]Nriagu et al. (1997a), [1]Omokhodion (1994); [2]Deveaux et al. (1986), [2]Grobler, Maresky & Kotze (1992), [2]Karimi et al. (1999), [2]Maresky & Grobler (1993), [2]Nriagu et al. (1997b), [2]von Schirnding et al. (2001), [2]White et al. (1982); [3]Koren et al. (1990), [3]Levallois et al. (1991), [3]Rhainds & Levallois (1993), [3]Smith & Rea (1995); [4]Centers for Disease Control and Prevention (2000, 2001); [5]Garcia & Mercer (2001); [6]Cordeiro, Lima Filho & Salgado (1996), [6]dos Santos et al. (1994), [6]Paolielo et al. (1997); [7]Sepulveda, Vega Morales & Delgado (2000); [8]Matte et al. (1991); [9]Azcona-Cruz et al. (2000), [9]Farias et al. (1998), [9]Hernandez-Avila et al. (1996), [9]Junco-Munoz et al. (1996), [9]Lacasaña-Navarro et al. (1996), [9]López Lara et al. (2000), [9]Romieu (2001), [9]Rothenberg et al. (1996); [10]Schutz et al. (1997); [11]Feo et al. (1993), [11]Mujica (2001); [12]Counter et al. (1998); [13]Bonilla, Mauss & Mauss (1998); [14]Jacoby (1998), [14]Ramirez, Paucar & Medina (1997); [15]Al-Saleh (1995), [15]Al-Saleh, Khalil & Taylor (1995); [16]Kamal, Eldamaty & Faris (1991); [17]Khassouani, Allain & Soulaymani (1997); [18]Bashir et al. (1995), [18]Hafeez & Malik (1996), [18]Khan et al. (1994, 1995), [18]M.A. Khwaja, unpublished data, 2002, [18]Sadaruddin et al. (1995); [19]Nielsen, Grandjean & Jorgensen (1998); [20]Flurin et al. (1998); [21]Jacob et al. (2000); [22]Vasilios et al. (1997); [23]Tepferberg & Almog (1999); [24]Bergdahl et al. (1997), [24]Osterberg et al. (1997); [25]Dutkiewicz, Sokolowska & Kulka (1993), [25]Osman et al. (1999), [25]Zedja et al. (1995, 1997); [26]Vural & Gulvendik (1988); [27]Blanusa et al. (1991), [27]Factor-Litvak et al. (1996, 1998), [27]Kostial et al. (1991); [28]Bitto, Horvath & Sarkany (1997); [29]R Kaufmann (unpublished data, 2001), [29]Tepferberg & Almog (1999); [30]Heinze et al. (1998); [31]Wananukul et al. (1998); [32]Kaiser et al. (2001); [33]Awasthi et al. (1996), [33]D'Souza, Narurkar & Narurkar (1994), [33]Gogte et al. (1991), [33]Lal et al. (1991), [33]Saxena et al. (1994), [33]Shenoi et al. (1991), [33]Wahid et al. (1997); [34]Australian Institute of Health & Welfare (1996); [35]Watanabe et al. (1996), [38]Yan et al. (1999), [35]Zhang et al. (1997); [36]Fawcett et al. (1996); [37]Chia et al. (1996, 1997), [37]Neo, Goh & Sam (2000); [38]Gao et al. (2001), [38]Murata et al. (1995), [38]Shen, Sheng & Yan (2001), [38]Shen et al. (1996), [38]Wan et al. (1996), [38]Zhang et al. (1997); [39]Kaufmann (2001); [40]Zhang et al. (1998); [41]Moon et al. (1995), [41]Yang et al. (1996).

The lead-induced disease burden was estimated according to the methods outlined in this guide. We only considered loss of IQ points if this loss resulted in MMR, and the number of people affected was determined on the basis of a standardized intelligence curve. To account for an increased prevalence in developing countries of risk factors that result in MMR, such as malnutrition and disease, we adjusted the prevalences of lead-induced MMR in such countries for the known ratio of mental retardation caused by other factors. Rates of lead-induced loss of IQ points and MMR are shown in Table A4.2, and rates of increased systolic blood pressure in adults are presented in Table A4.3.

Table A4.2 Proportion affected by loss of IQ points and MMR incidence rates in children (0-1 years old) due to lead exposure in the year 2000

Region	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Loss of IQ points (proportion per 1000)														
0.65	186	191	124	222	232	233	181	227	227	236	218	192	141	218
1.95	66	61	33	104	105	102	66	41	92	106	76	61	23	75
3.25	34	28	14	59	58	54	35	10	46	57	36	28	6	34
3.5	139	95	21	167	172	114	172	5	89	119	65	83	3	58
Totals	425	375	192	552	567	503	454	283	454	518	395	364	173	385
Mild mental retardation (mean incidence rate per 1000 children)														
Best estimate	7.5	5.8	1.1	13.2	10.2	7.6	8.0	1.1	5.2	4.9	8.7	5.5	0.7	7.7
Lower estimate	4.2	3.0	0.5	7.0	5.3	3.6	4.6	0.3	2.4	2.3	3.9	2.8	0.2	3.4
Upper estimate	12.5	10.0	2.1	22.0	17.2	13.3	13.0	2.7	9.3	8.6	16.3	9.7	1.7	14.6

Table A4.3 Incidence rates of increased systolic blood pressure in adult men and women (ages 20–79 years) caused by environmental exposure to lead in 2000

	Incidence rate per 1000													
Region	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Incremental increase														
0.625 mmHg in males, 0.4 mmHg in females	185	191	91	221	226	233	181	243	225	236	218	62	141	206
1.875 mmHg in males, 1.2 mmHg in females	66	61	23	108	106	102	66	46	106	106	76	29	17	61
3.125 mmHg in males, 2.0 mmHg in females	34	28	9	63	60	54	35	11	61	57	36	97	3	24
3.75 mmHg in males, 2.4 mmHg in females	143	98	11	199	201	114	172	6	155	119	65	97	1	28
Totals	428	378	134	591	593	503	454	306	547	518	395	285	162	319

The rates in Tables A4.2 & A4.3 can be converted into disease burden, measured in the number of deaths and DALYs (disability-adjusted life years). For example, the disease burden from lead-induced mental retardation is equivalent to 9.8 million DALYs, and that from cardiovascular diseases due to elevated blood pressure equivalent to 250 000 premature deaths and 3.5 million DALYs (Table A4.4).

Table A4.4 DALYs and deaths caused by lead-induced MMR and cardiovascular disease (CVD)

Region	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB	World
DALYs due to MMR (in thousands)															
	871	768	82	1393	225	334	868	55	212	153	582	1912	16	2361	9813
DALYs due to CVD (in thousands)															
IHD[1]	44	38	19	112	12	51	125	30	125	249	49	447	3	86	1391
CVA[2]	58	60	10	134	16	19	70	25	111	196	54	250	6	256	1266
HTD[3]	16	17	4	46	10	16	34	3	33	22	25	46	0	57	329
OCD[4]	10	9	2	12	2	4	11	4	11	15	5	32	0	8	126
Totals[5]	128	124	35	304	40	90	241	63	280	482	133	775	9	407	3112
CVD mortality (deaths in thousands)															
Totals	8	8	2	20	3	6	17	5	22	39	9	57	1	31	229

[1] ischaemic heart disease [2] cerebrovascular disease [3] hypertensive disease
[4] other cardiac diseases [5] total cardiac diseases

Tables A4.5 and A4.6 summarize the rates of people at risk of gastrointestinal effects and anaemia at any point in time, assuming that people are not removed from the source, or treated to reduce their lead levels. The disease burden in DALYs has not yet been assessed for these two conditions, since the burden of these disease categories has not yet been estimated at global level.

Table A4.5 Number of people per 1000 affected by anaemia caused by environmental exposure to lead in 2000

	Number of people affected per 1000													
Region	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Children														
Best estimate	10	6	0	6	7	2	14	0	2	2	1	5	0	1
Lower estimate	4	3	0	2	2	0	6	0	0	0	0	2	0	0
Upper estimate	20	13	1	16	18	8	27	0	6	9	5	10	0	4
Adults														
Best estimate	9	6	0	7	8	2	13	0	3	2	1	6	0	0
Lower estimate	4	2	0	2	2	0	5	0	0	0	0	2	0	0
Upper estimate	18	12	0	18	21	7	25	0	12	7	4	12	0	1

Table A4.6 Number of children per 1000 affected by gastrointestinal effects in from environmental exposure to lead in 2000

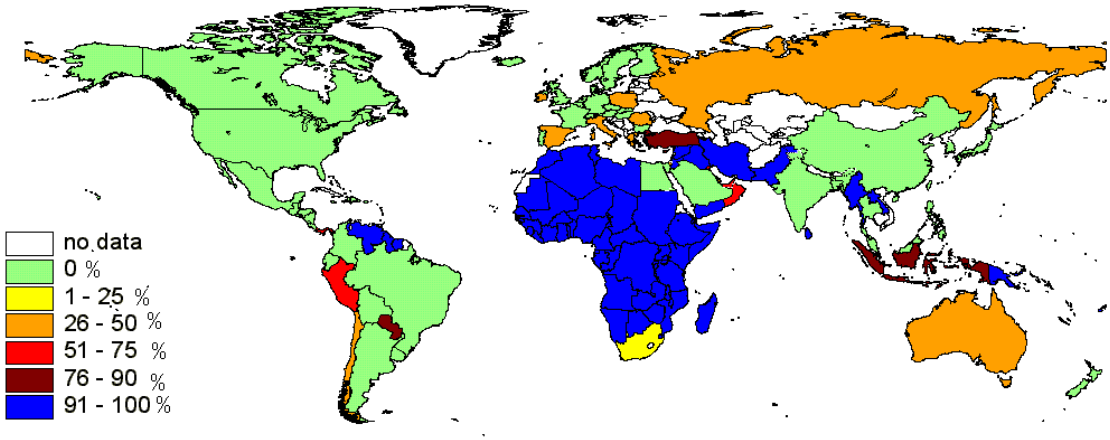
	Regions/ rates per 1000													
	AfrD	AfrE	AmrA	AmrB	AmrD	EmrB	EmrD	EurA	EurB	EurC	SearB	SearD	WprA	WprB
Best estimate	12	7	0	8	9	3	16	0	2	3	2	6	0	1
Lower estimate	5	3	0	2	3	0	7	0	0	0	0	2	0	0
Upper estimate	22	14	1	20	22	11	30	0	8	11	6	11	0	5

[1] Rates per 1000 children.

Together, MMR and increased systolic blood pressure account for approximately 0.9% of the global burden of disease. As several outcomes caused by lead could not be quantified in this analysis (in particular, increased delinquent behaviour and its impact on injuries), the true burden probably exceeds 1.0%. Health impacts from anaemia and gastrointestinal effects are relatively small.

Lead in the environment is still a major risk factor and its effects are mainly concentrated in developing countries. The disease burden associated with environmental exposure to lead could be virtually eliminated through interventions that have proven successful in developed countries, most importantly the removal of lead from gasoline (see current status in Figure A4.2). The burden of disease due to environmental lead exposure is likely to be underestimated because of a lack of data; the exclusion of geographical "hotspots"; the adoption of conservative assumptions; and because a number of health outcomes and social consequences of lead exposure could not be quantified due to insufficient evidence (e.g. increased risk of criminality and drug abuse).

Figure A4.2 Sales of leaded gasoline as a percentage of total gasoline sales, by country[1]



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

[1] Source: Walsh (2001).

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Annex 5 Calculation spreadsheet for lead

Two spreadsheets based on Microsoft Excel are available to assist in calculating the burden of disease from lead:

1. The "lead spreadsheet", to estimate morbidity, mortality and the attributable fraction of disease due to lead (available on request from: ebd@who.int).
2. The "DALY calculation template", to convert disease incidence and deaths into DALYs. This is available on: www.who.int/evidence/nbd, under "other files".

The parameters required to estimate disease burden from lead, using the two spreadsheets, are briefly described below. In addition, WHO assists countries to establish their own burden of disease estimates (see Chapter 5, or ebd@who.int).

Required input parameters for the lead spreadsheet

- one or more parameters from a blood lead study that represent the population to be assessed (e.g. mean, standard deviation and sample size);
- the population size for the age groups 0–4 years, 5–14 years and older than 15 years;
- the percentage of the population to be assessed that is urban.

Output parameters of the lead spreadsheet

- the incidence rates per 1000, for lead-induced MMR, anaemia and gastrointestinal effects;
- the attributable fraction of ischaemic heart disease, cerebrovascular disease, hypertensive disease and "other cardiac diseases" (which can be multiplied by the disease burden data per disease to obtain the attributable burden).

Input parameters for the DALY calculation template

- population per age group;
- severity weight (0.361 for MMR);
- incidence rates per 1000, for lead-induced MMR, anaemia and gastrointestinal effects;
- duration of the illness.

Output parameters of the DALY calculation template

- MMR measured in DALYs.