

Burden of disease attributable to selected environmental factors and injury among children and adolescents in Europe

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Summary

Background Environmental exposures contribute to the global burden of disease. We have estimated the burden of disease attributable to outdoor and indoor air pollution, inadequate water and sanitation, lead exposure, and injury among European children and adolescents.

Methods Published studies and reports from international agencies were reviewed for calculation of risk-factor exposure in Europe. Disability-adjusted life years (DALYs) or deaths attributable to each factor, or both, were estimated by application of the potential impact fraction to the estimates of mortality and burden of disease from the WHO global database of burden of disease.

Findings Among children aged 0–4 years, between 1·8% and 6·4% of deaths from all causes were attributable to outdoor air pollution; acute lower-respiratory-tract infections attributable to indoor air pollution accounted for 4·6% of all deaths and 3·1% of DALYs; and mild mental retardation resulting from lead exposure accounted for 4·4% of DALYs. In the age-group 0–14 years, diarrhoea attributable to inadequate water and sanitation accounted for 5·3% of deaths and 3·5% of DALYs. In the age-group 0–19 years, injuries were the cause of 22·6% of all deaths and 19·0% of DALYs. The burden of disease was much higher in European subregions B and C than subregion A. There was substantial uncertainty around some of the estimates, especially for outdoor air pollution.

Interpretation Large proportions of deaths and DALYs in European children are attributable to outdoor and indoor air pollution, inadequate water and sanitation, lead exposure, and injuries. Interventions aimed at reducing children's exposure to environmental factors and injuries could result in substantial gains. The pronounced differences by subregion and age indicate the need for targeted action.

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Introduction

Concern about the effects on children's health of unsafe and unhealthy environments and a commitment to action has lately been expressed at international level.¹ The concern stems from increasing evidence that children are especially susceptible and may be more exposed than adults to many adverse environmental factors including: unsafe home environments; road traffic; chemical and microbiological contamination of air, water, food, and soil; and physical agents such as radiation and noise.^{2,3} Worldwide, an estimated 40% or more of the environmental burden of disease (EBD) falls on children under 5 years of age.⁴

Generally, children living in the 51 countries of the WHO European region enjoy better health than those living in other regions, but they are not exempt from the effects of unsafe and unhealthy environments. Furthermore, poverty, a powerful determinant of environmental exposure, affects a substantial proportion of children in the region.⁵ Although there is increasing evidence on the association between children's exposure to environmental toxicants and health effects,³ the magnitude and geographical distribution of EBD among children (0–19 years) in the WHO European region have not been assessed so far.

To provide the knowledge base for the development of the children's environment and health action plan for the European region (CEHAPE), which will be discussed and negotiated at the Fourth Ministerial Conference on Environment and Health to be held in Budapest, Hungary, in June, 2004,⁶ we assessed the EBD in terms of deaths and disability-adjusted life years (DALYs)^{7,8} among children and adolescents. Our assessment was restricted to four major environmental risk factors (outdoor air pollution, indoor air pollution, inadequate water and sanitation, and lead) and injuries, which represent the main environmental risk factors globally⁹ and for which available data are sufficient for large-scale estimates.

Methods

The methods of the study and data sources^{10–15} are summarised in table 1.

Study population

We estimated the burden of disease attributable to outdoor and indoor air pollution, inadequate water and sanitation, lead exposure, and injuries for children in three European subregions, as defined by WHO on the basis of child mortality before 5 years of age and 15–59-year-old male mortality: EurA (very low child mortality, very low adult mortality), EurB (low child mortality, low adult mortality), and EurC (low child mortality, high adult mortality).¹⁶ WHO member states included in each subregion are shown in the figure.

The age-groups included in the analyses were 0–4 years, 5–14 years, and 15–19 years. Since data on

Risk factor	Outcome	Age-group (years)	Estimation method	Sources of information		
				Population exposure	Relative risk	Total burden
Outdoor air pollution	Death from any cause Death from acute respiratory-tract infection	0–4	Indirect, exposure-based	World Bank ¹⁰ Review of published literature*	Ostro ¹¹	GBD 2001 estimates ¹²
Indoor air pollution	Acute lower-respiratory-tract infection	0–4	Indirect, scenario-based	Estimates by Smith et al ¹³	Smith et al ¹³	GBD 2001 estimates ¹²
Inadequate water and sanitation	Diarrhoea	0–14	Indirect, scenario-based	Prüss et al ¹⁴	Prüss et al ¹⁴	GBD 2001 estimates ¹²
Lead	Mild mental retardation	0–4	Direct	Review of published literature*	Schwartz ¹⁵	..
..	Injury	0–19	..	..	..	GBD 2001 estimates ¹²

*<http://image.thelancet.com/extras/04art3073webfr.pdf> lists the references.

Table 1: Summary of study methods and data sources

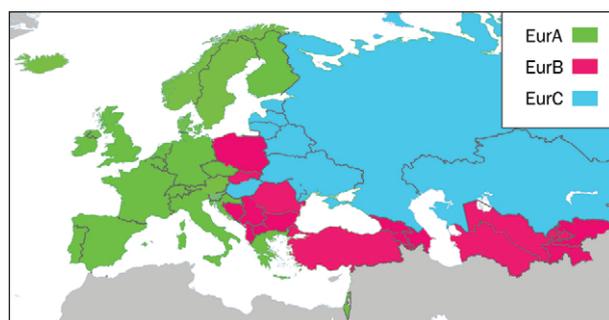
exposures and health effects were not available for all age-groups, and because some health effects are confined to specific age-groups, the estimation of the burden of disease did not include the whole 0–19-year age range for all risk factors.

Disease outcomes

For each risk factor, we estimated the burden of disease only for a limited number of disease outcomes. In particular, we estimated the burden of disease for outcomes and in age-groups for which there is strong evidence of an association: mortality from all causes and from acute respiratory-tract infections attributable to outdoor air pollution in children aged 0–4 years;^{17–19} acute lower-respiratory-tract infections attributable to indoor air pollution among children aged 0–4 years;²⁰ diarrhoeal disease resulting from inadequate water and sanitation among children aged 0–14 years;^{14,21} mild mental retardation due to lead exposure among children aged 0–4 years;²² and injuries among children aged 0–19 years. We report deaths as well as DALYs as estimates of the burden of disease.

Estimates of EBD

Each year WHO compiles the global burden of disease (GBD) as DALYs by sex, age, and geographical region. For this study, GBD 2001 estimates of DALYs and deaths¹² were reported directly only for injuries. To estimate the burden of disease attributable to the other



Definition of the three European WHO subregions

EurA includes: Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, UK; child population 0–19 years, 94 994 000. EurB includes: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Serbia and Montenegro, Slovakia, Tajikistan, the former Yugoslav republic of Macedonia, Turkey, Turkmenistan, Uzbekistan; child population 0–19 years, 79 467 000. EurC includes: Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine; child population 0–19 years, 64 846 000. Source—United Nations Population Division. World Population Prospects: The 2002 Revision Population Database.

environmental risk factors, we used indirect and direct methods, depending on the type of risk factor and disease outcome and on data availability.

Indirect method

The indirect method used the distribution of risk-factor exposure within the study population, the exposure–response relation for the risk factor, and the DALYs lost due to the disease for the risk factor of interest, or other epidemiological information if DALYs were not available, such as mortality rates or disease incidence. For a given population, if the first two variables (distribution of exposure and exposure–response relation) are known, they can be used to estimate the impact fraction (IF) which is then applied to the disease estimates.

Two different approaches were chosen to describe the exposure–response relation. When we could specify a continuous numerical relation between the proximal cause and its outcomes, we used the exposure–based approach. Otherwise, we adopted the scenario-based approach, which ascribes the population to a characteristic exposure scenario defined by typical combinations of risk factors encountered in the population. Risk information is then obtained from published evidence and matched to the appropriate scenario.

By use of counterfactual analysis,⁸ we estimated the contribution of a risk factor to disease morbidity or mortality by comparing the current disease burden with what would be realistically achievable after interventions or with the theoretical minimum (“the counterfactual”). From the distribution of risk-factor exposure in the population and the exposure–response information we calculated the IF.⁸ We then obtained the burden of disease attributable to the risk factor by multiplying the total disease burden by the IF.

Sensitivity analyses were done by calculation of lower and upper estimates of the burden of disease based on the confidence limits of the relative risk or on the assumption of different population exposure distributions or scenarios.

Direct method

The direct method did not require the application of an IF to a known total burden. By contrast, the burden of disease and death attributable to a certain risk factor was calculated directly starting from the exposure distribution in the population, the incidence rate of disease, age at onset, duration, and disability weight.

The DALYs were calculated as the sum of years of life lost due to premature mortality and years lived with disability. We applied time discounting and age weighting to these variables for comparability with the WHO standards.

Risk factor	Type of exposure measure	EurA	EurB	EurC
Outdoor air pollution	PM10 outdoor concentration ($\mu\text{g}/\text{m}^3$)	24.84* 35.96†	67.01* 53.86†	55.67* 61.00†
Indoor air pollution	Prevalence of exposure to smoke from indoor solid-fuel use (% of households using solid fuels x ventilation factor)	0	20.5	6.4
Inadequate water and sanitation	% of population in scenarios I–VI (as defined in text)	100% in II	12% in VI 1% in Vb 8% in Va 79% in IV	1% in VI 5% in Va 94% in IV
Lead	Blood lead concentration ($\mu\text{g}/\text{L}$)	28‡ 45§	39‡ 149||	62‡ 55§

*Average PM10 concentration calculated from the World Bank estimates.¹⁰

†Average PM10 concentration calculated from epidemiological studies (<http://image.thelancet.com/extras/04art3073webfr.pdf>). ‡Mean blood lead concentration in urban areas and §in rural areas

(<http://image.thelancet.com/extras/04art3073webfr.pdf>). ||Blood lead concentrations based on a single study.²⁶

Table 2: Estimates of children's exposure to four environmental risk factors in the European subregions

Risk factors

Outdoor air pollution

The outcome analysed was mortality for children aged 0–4 years attributable to short-term exposure to outdoor air pollution, measured as PM10 outdoor air concentration. The indirect estimation method with an exposure-based approach was used. Two different sets of exposure data were used for the calculations. The first was average PM10 concentrations estimated by the World Bank based on a model including demographics, energy consumption, level of economic development, and geographical and meteorological variables.¹⁰ The second was PM10 concentrations measured by fixed-site monitors and reported in studies carried out during the past 10 years (references listed at <http://image.thelancet.com/extras/04art3073webfr.pdf>). The exposure–response relation for

outdoor air concentrations of PM10 and the selected health effect was modelled on the basis of relevant epidemiological studies.^{17–19,23,24} This model estimated that an increase of $10 \mu\text{g}/\text{m}^3$ in ambient PM10 concentration results in a 1.66% (95% CI 0.34–3.00) increase in daily mortality (from all causes, according to a less conservative interpretation, or from acute respiratory-tract infections, according to a more conservative one) for children aged 0–5 years.¹¹ The IF was applied to the baseline mortality rate reported in the 2001 GBD study.¹² Since the outcome of the studies used to estimate the dose–response relation was death from all causes in some cases^{18,19} and death from acute respiratory-tract infections in others,^{17,23,24} we carried out the analysis twice by applying the estimated relative risk to both outcomes. Each analysis was repeated with two different PM10 threshold concentrations (or counterfactual exposures): the first ($10 \mu\text{g}/\text{m}^3$) was the concentration there would be with no man-made pollution; in this case what we calculated can be considered as the attributable mortality. The second ($20 \mu\text{g}/\text{m}^3$) was the PM10 annual mean target set for the year 2010 by the European Union;²⁵ in this case what we calculated can be considered as the avoidable mortality. In addition to calculating the burden of disease for different categories of exposure to PM10, we did sensitivity analyses based on the 95% CI of the estimate of the dose–response relation.

Indoor air pollution

The outcome analysed was acute lower-respiratory-tract infection among children aged 0–4 years, attributable to exposure to indoor smoke from solid fuels. The indirect estimation method with the scenario-based approach was used. We used the estimates of child exposure from a recent meta-analysis,¹³ which estimated exposure to solid fuels in the population as the product of the proportion of households using solid fuels and a factor reflecting both

Subregion	Deaths			DALYs		
	Number	% from all causes	Number per 10 000 children	Number	% from all causes	Number per 10 000 children
Outdoor air pollution (0–4 years)*						
A	178 [3]	0.8 [<0.1]	0.08 [0]	..	..	..
B	10 617 [3387]	7.5 [2.4]	5.91 [1.88]	..	..	..
C	3001 [471]	5.8 [0.9]	2.64 [0.42]	..	..	..
Total	13 796 [3861]	6.4 [1.8]	2.68 [0.75]	..	..	..
Indoor air pollution (0–4 years)†						
A	0	0	0	0	0	0
B	9289	6.6	5.17	321 483	5.0	178.90
C	556	1.1	0.49	19 335	0.7	17.04
Total	9845	4.6	1.91	340 818	3.1	66.13
Inadequate water and sanitation (0–14 years)‡						
A	63	0.2	0.01	25 946	0.8	3.71
B	11 876	7.5	2.01	446 763	5.2	75.75
C	1609	2.4	0.36	77 231	1.6	17.04
Total	13 548	5.3	0.78	549 940	3.5	31.57
Lead (0–4 years)§						
A	..	..	..	39 458	2.3	17.76
B	..	..	..	300 913	4.5	167.45
C	..	..	..	142 521	5.0	125.59
Total	..	..	..	482 892	4.4	93.70
Injuries (0–19 years)						
A	13 450	30.2	1.42	894 947	14.9	94.21
B	18 933	10.7	2.39	1 528 037	13.8	192.53
C	42 776	38.8	6.60	2 370 573	29.1	365.58
Total	75 159	22.6	3.14	4 793 557	19.0	200.39

*The results refer to the analysis based on current PM10 concentrations calculated from the World Bank estimates¹⁰ and with as the counterfactual exposure a PM10 concentration of $20 \mu\text{g}/\text{m}^3$. [Results in brackets represent values obtained by application of the relative risk for outdoor air pollution to deaths from acute respiratory-tract infections only.] †The counterfactual scenario was that no households used solid fuels. ‡These results were obtained by the indirect method. The counterfactual scenario is 100% of the population in scenario I (ideal situation). §The counterfactual exposure is $0.16 \mu\text{g}/\text{L}$ (blood lead concentration in preindustrial people).

Table 3: Deaths and DALYs attributable to selected environmental factors among children and adolescents in the European region

External cause	% of injuries attributable to cause					
	Deaths			DALYs		
	0–4 years (n=12 874)	5–14 years (n=15 578)	15–19 years (n=46 706)	0–4 years (805 420)	5–14 years (n=1 671 056)	15–19 years (n=2 317 081)
Road-traffic accident	13.5	28.1	26.0	9.7	15.6	22.5
Poisoning	8.8	5.9	11.2	5.0	2.2	7.6
Fall	5.5	3.8	2.6	16.4	16.6	8.3
Fire	16.5	5.8	3.0	14.3	4.8	2.8
Drowning	14.6	19.9	5.5	8.3	7.0	3.7
Other unintentional	35.3	20.9	13.7	40.7	39.9	21.1
Self-inflicted injury	0	9.2	22.4	0	6.9	15.9
Violence	4.8	4.8	10.9	2.9	4.5	13.5
War	0.3	1.3	4.5	1.7	2.4	4.3
Other intentional	0.9	0.2	0.2	1.0	0.1	0.1

Table 4: Distribution of deaths and DALYs from injury by external cause and age-group in the European region

ventilation-related and stove characteristics. From this meta-analysis,¹³ the relative risk estimating the association between the exposure and acute lower-respiratory-tract infections in children aged 0–4 years was 2.3 (95% CI 1.9–2.7). The burden of acute lower-respiratory-tract infection to which the IF was applied was obtained from the 2001 GBD statistics.¹² Uncertainty was expressed by lower and upper estimates based on the 95% CI values of the relative risks.

Inadequate water and sanitation

The outcome considered was diarrhoea in children aged 0–14 years, attributable to inadequate water and sanitation. Both the direct method and the indirect method with a scenario-based approach were used. The burden of disease from water, sanitation, and hygiene has been estimated at the global level according to various scenarios characterised by different faecal-oral pathogen loads based on combinations of risk factors and policy situations.¹⁴ Scenario I represents the ideal situation (relative risk 1.0) where there is no transmission of diarrhoeal disease through water and sanitation. In scenario II (relative risk 2.5), there is regulated water supply and full sanitation coverage, with partial treatment for sewage. For both scenario IV, with improved water supply and basic sanitation, and scenario Va, with basic sanitation but no improved water supply, the relative risk is 6.9.¹⁴ Scenario Vb (relative risk 8.7) has improved water supply and no basic sanitation, and scenario VI (relative risk 11.0) is without improved water supply, and basic sanitation. Scenario III is irrelevant to this study.¹⁴ For the indirect method, we applied the impact fraction of diarrhoeal disease due to inadequate water and sanitation to the 2001 GBD estimates of deaths and DALYs.¹² For the direct method, we estimated the number of DALYs taking into account diarrhoeal disease incidence, case-

fatality, and duration and its severity weight.⁸ We estimated case-fatality rates combining 2001 GBD death estimates¹² with 1990 Global Health Statistics incidence estimates.²⁷

Lead

The outcome considered was mild mental retardation (defined as an IQ between 50 and 70) among children aged 0–4 years attributable to exposure to lead.¹⁵ The direct method was used to calculate DALYs. We reviewed published evidence so that we could estimate mean blood lead concentrations in children of the three European subregions (<http://image.thelancet.com/extras/04art3073webfr.pdf>). We excluded studies that were undertaken near lead or metal mining or smelting environments or for which mean lead concentrations were not reported, and we accounted for the decreases in blood lead concentrations that might have occurred between each study year and 2001 owing to the implementation of lead phase-out in petrol in some countries.²⁸ We adjusted the regional means of blood lead concentrations for the documented effects of lead prevention programmes.²² We estimated the proportion of the child population with blood lead concentrations within the ranges 50–100 µg/L, 101–150 µg/L, 151–200 µg/L, >200 µg/L, associated with the loss of 0.65, 1.95, 3.25, and 3.50 IQ points, respectively^{15,22}) and the frequency of mild mental retardation in each subregion. DALYs were estimated from the frequency of mild mental retardation, age at onset, duration, and a disability weight. We did sensitivity analyses with different assumptions about lead prevention programmes.

Injury

The burden of injury was calculated from GBD 2001 estimates¹² by external injury cause including: road-traffic accidents (codes E810–819, E826–829 in the

Factor	% of deaths from all causes			% of DALYs from all causes		
	0–4 years	5–14 years	15–19 years	0–4 years	5–14 years	15–19 years
Outdoor air pollution*	6.4 [1.8]	..	..	..	..	..
Household solid-fuel use†	4.6	..	..	3.1	..	..
Inadequate water and sanitation‡	9.6	0.8	..	7.9	1.0	..
Lead§	..	..	..	4.4	..	..
Injuries	6.0	41.2	59.9	7.3	29.8	27.1
All	26.5 [21.9]	42.1	59.9	22.7	30.8	27.1
Absolute number of deaths and DALYs from all causes	216 194	37 784	77 952	10 997 728	5 604 270	8 564 440

*The results refer to the analysis based on current PM10 concentrations calculated from World Bank estimates¹⁰ and with as the counterfactual exposure a PM10 concentration of 20 µg/m³. [Results in brackets represent values obtained by application of the relative risk for outdoor air pollution to deaths from acute respiratory-tract infections only.] †The counterfactual scenario was that no households used solid fuels. ‡The results were obtained by the indirect method. The counterfactual scenario is 100% of the population in scenario I (ideal situation). §The counterfactual exposure is 0.16 µg/L.

Table 5: Deaths and DALYs attributable to selected environmental factors as a proportion of deaths and DALYs from all causes among children and adolescents in the European region by age-group

Subregion and threshold ($\mu\text{g}/\text{m}^3$)	Estimate of deaths: relative risk applied to mortality from any cause						Estimate of deaths: relative risk applied to mortality from acute respiratory-tract infections only					
	Current PM10 estimated from the World Bank ⁴⁰			Current PM10 estimated from epidemiological studies*			Current PM10 estimated from the World Bank ⁴⁰			Current PM10 estimated from epidemiological studies*		
	Central	Lower	Upper	Central	Lower	Upper	Central	Lower	Upper	Central	Lower	Upper
EurA												
10	541	112	969	938	195	1667	10	2	19	18	4	32
20	178	37	321	582	120	1040	3	1	6	11	2	20
EurB												
10	12 770	2715	22 232	9931	2093	17 436	4074	866	7092	3168	668	5562
20	10 617	2242	18 602	7730	1619	13 660	3387	715	5934	2466	516	4358
EurC												
10	3811	804	6684	4237	897	7406	598	126	1048	665	141	1162
20	3001	629	5298	3435	732	6042	471	99	831	539	113	948

*<http://image.thelancet.com/extras/04art3073webfr.pdf>.

Table 6: Sensitivity analyses for outdoor air pollution and deaths

International Classification of Disease, ninth revision), poisonings (E850–869), falls (E880–888), and drownings (E910) among unintentional injuries, and self-inflicted injuries (E950–959), violence (E960–969), and war (E990–999) among intentional injuries. The burden of other unintentional (E800–807, E820–848, E870–879, E900–909, E911–949) and intentional injuries (E970–978) is also reported.

Role of the funding source

The European Centre for Environment and Health, Rome Office of the WHO Regional Office for Europe participated in the design and review of the study.

Results

Children's exposures to the main environmental factors by subregion are reported in table 2. Children in subregions EurB and EurC had greater exposure to outdoor and indoor air pollution, inadequate water and sanitation, and lead than children in EurA.

In the European region as a whole, we estimated that in the age-group 0–4 years, 6.4% of all deaths (or 1.8% by application of the relative risk for outdoor air pollution to deaths due to acute respiratory-tract infections only) are attributable to outdoor air pollution and 4.6% to indoor air pollution from use of solid fuels. In the age-group 0–14 years, 5.3% of all deaths are attributable to inadequate water and sanitation. In the age-group 0–19 years, 22.6% of all deaths are attributable to injuries (table 3). In children aged 0–4 years, indoor air pollution and lead accounted for 3.1% and 4.4% of all DALYs, respectively. In the age-group 0–4 years, mortality rates per 10 000 children were highest in EurB for all factors except injuries (table 3). In this age-group, injuries were more frequent in EurC (5.07 in EurC, 3.07 in EurB, 0.72 in EurA). In the age-group 0–4 years, the deaths and DALYs per 10 000 children attributable to the five causes combined were higher in EurB (23.94 deaths [19.98 by application of the relative risk for outdoor air pollution to deaths due to acute respiratory-tract infections only] and 937.31 DALYs per 10 000 children) than in EurC (10.93 deaths [8.70] and 549.45 DALYs per 10 000) or EurA (0.82 deaths [0.74] and 86.27 DALYs per 10 000). However, EurC had the highest rates in the age-groups

Subregion	Estimate of deaths			Estimate of DALYs		
	Central	Lower	Upper	Central	Lower	Upper
EurA	0	0	0	0	0	0
EurB	9289	6876	11 409	321 483	237 973	394 837
EurC	556	394	710	19 335	13 710	24 700

Table 7: Sensitivity analyses for indoor air pollution and deaths and DALYs from acute lower-respiratory-tract infections

5–14 years (2.43 deaths and 222.23 DALYs per 10 000) and 15–19 years (14.80 deaths and 681.04 DALYs per 10 000), and these were due mainly to injuries.

Table 4 shows the distribution of deaths and DALYs from injury by age-group and external cause. In the age-group 0–4 years, 94% of accidental deaths and DALYs were a consequence of unintentional injuries. With increasing age, the proportion of deaths and DALYs due to unintentional injuries decreased (85% and 86%, respectively, in the age-group 5–14 years and 62% and 66% in the age-group 15–19 years).

In subregions EurA and EurC, the highest numbers of deaths and DALYs per 10 000 children were in the age-group 15–19 years; these were entirely attributable to injuries. In EurB, by contrast, the highest rates were in the age-group 0–4 years, in which both outdoor and indoor air pollution and inadequate water conditions accounted for a greater proportion of deaths and DALYs than injuries.

In the European region as a whole, the five outcomes analysed in this study accounted for 26.5% of deaths from all causes (21.9% by application of the relative risk for outdoor air pollution to deaths due to acute respiratory-tract infections only) and 22.7% of all DALYs among children aged 0–4 years (table 5).

Results of sensitivity analyses are given in tables 6–9. For outdoor air pollution, use of PM10 estimates from epidemiological studies instead of those from the World Bank increased the number of deaths attributable to outdoor air pollution in subregions EurA and EurC and decreased the number in EurB (table 6). In both analyses, there was a substantial uncertainty around the estimates owing to the wide range of dose-response effect.

For indoor air pollution, the upper estimate of the burden of acute lower-respiratory-tract infections was about twice the lower estimate (table 7). The burden of diarrhoeal disease attributable to inadequate water and sanitation varied with the estimation method used,

Region and method	Estimate of deaths			Estimate of DALYs		
	Central	Lower	Upper	Central	Lower	Upper
EurA						
Indirect	63	..	..	25 946	..	..
Direct	60	..	..	29 602	..	..
EurB						
Indirect	11 876	10 374	12 831	446 763	390 276	482 710
Direct	17 753	9077	45 404	721 650	366 769	1 834 545
EurC						
Indirect	1609	1385	1759	77 231	66 455	84 416
Direct	3230	1562	7934	174 530	84 372	428 629

Table 8: Sensitivity analyses for inadequate water and sanitation and diarrhoea deaths and DALYs

Region	Best estimate of LPP	LPP in all countries	LPP in no country
EurA	39 458	33 821	42 277
EurB	300 913	284 950	312 312
EurC	142 521	112 290	148 280

LPP=lead prevention programme.

Table 9: Sensitivity analyses for lead exposure and DALYs due to mild mental retardation

especially in EurB and EurC (table 8). Use of different assumptions on the existence of lead exposure prevention programmes caused little variation in the burden of disease attributable to lead (table 9).

Discussion

Our study provides an assessment of the effect of environmental factors on children's health in the European region. A limited number of environmental factors and disease outcomes were included in the analyses, owing to the lack of valid exposure data and strong evidence of exposure-response relations. For example, lack of safe water and sanitation and air pollution contribute to undernutrition and chronic respiratory disease,⁴ but these disease outcomes could not be included in the analysis. Also, we could not assess the health effects of exposure during the lifespan from the prenatal period to adolescence to other contaminants of air, water, food, and soil, such as polychlorinated biphenyls and pesticides, or physical agents such as ionising and non-ionising radiation. Insufficient data and the difficulty of assessing outcomes such as cancer, which may be manifest only in adult life,³ make assessment of the magnitude of several of these effects even more challenging. Therefore, our EBD study estimates only part, although a major one, of the total influence of environmental exposures on children's health. For indoor air pollution, we could not include in the analyses all sources of contamination, such as environmental tobacco smoke, organic asthma-related pollutants, cooking-oil and kerosene smoke, and volatile organic compounds, nor take into account the very small numbers of people in EurA who are exposed to solid-fuel smoke. This inability explains the zero estimate of deaths and DALYs in EurA.

We showed that, in the region as a whole, air pollution, inadequate water and sanitation, lead exposure, and injuries account for a significant proportion of burden of disease and deaths from all causes. The EBD is much greater in EurB and EurC than in EurA, owing to a much higher burden of disease attributable to air pollution and inadequate sanitation, but also to a higher burden of disease from lead exposure and injuries. The burden of disease attributable to inadequate water and sanitation is greater among children aged 0-4 years, whereas the burden of injuries is particularly high in the age-groups 5-14 years and 15-19 years. These striking differences across the region and among age-groups should be taken into account for targeting of interventions.

For this study we adopted the burden of disease methods, which allow quantification of risk factors to health in a comparative and internally consistent way.⁸ Also, for the sake of consistency with similar approaches,⁹ we adhered to the original definition of European subregions developed by WHO. We chose this approach to ensure consistency with current assessments of the international burden of disease and risk factors, but it has some limitations.

The WHO classification of subregions is based on both child and adult mortality rates. The latter are less able than the former to capture the differences in the political, economic, and social systems of a given country that

determine to a large extent the exposures and risks of a population. In the European region this classification may produce unlikely groupings. For example, central Asian republics, which have many similarities, are split into the B and C subregions, and Poland and the Baltic countries are in subregions B and C, respectively. A classification based on child mortality alone would have corresponded better to the socioeconomic and environmental context of the countries. Thus, although estimates on EurA can be generalised to all countries of the subregion, which represent a fairly homogeneous group, the same is not as true for estimates in subregions B and C. Estimates were skewed towards those countries with the highest child mortality and absolute number of children. For example, the higher burden of disease for indoor and outdoor air pollution and water and sanitation in EurB is strongly influenced by the fact that this subregion includes countries with the highest child mortality in the whole region.

The results are also likely to be skewed towards the countries with available data. There is a scarcity of available publications on many countries in EurB and EurC. For example, blood lead concentrations in rural areas were unexpectedly high in EurB because they were based on one small study sample in a rural population in Bulgaria.²⁶ Since even small changes in exposure estimates can greatly influence estimates of deaths and DALYs, more uniform and comprehensive collection of environmental exposure data as well as regional standardisation and routine collection of morbidity and mortality statistics are urgently needed for improved EBD estimates.

Estimates of the exposure and dose-response relation for some factors (eg, inadequate water and sanitation), were largely based on the findings of studies carried out in less developed countries, thus their extrapolation to countries in the European region could be questioned. However, there are several countries in this region where housing and sanitation conditions are similar to those in less developed countries. For example, in the Global Water and Sanitation Assessment, estimates of water and sanitation coverage in Romania are similar to those of many less developed countries.²⁹

In our analysis there are several potential sources of error and uncertainty, such as bias (eg, from different methods for measuring exposures), confounding (eg, from socioeconomic status), effect modification (eg, from access to and quality of health care), and statistical error.³⁰ In our sensitivity analysis, we dealt exclusively with uncertainties in the estimates of exposures and dose-response relations and we restricted our analyses to a limited range of possibilities. For example, the estimates of exposures to outdoor air pollution used only two different sets of sources to derive overall averages of exposure across large areas; we did not consider the intraregional variations in exposure that can be substantial.³¹ Even so, there was much variability around most of our EBD estimates. For example, for outdoor air pollution, the central estimates obtained from the two sets of exposure data differed, on average, by a factor of 1.5. The uncertainty based on the range of the dose-response relation was even greater, the upper estimates being eight times the lower estimates. Furthermore, the results depend on whether the relative risk is applied to deaths from any cause or those from acute respiratory-tract infections only. The limitations in our approach add to the more general difficulties in the estimation and interpretation of burden of disease measures, which have been discussed elsewhere.³²

Despite these limitations, our findings indicate the urgent need for interventions aimed at reducing children's exposure to unsafe water, outdoor and indoor air pollution, and lead, and at preventing injuries. Action can result in substantial public-health gains. For example, various studies have shown that better housing, safer water and sanitation, and cleaner fuels strongly contribute to better child health.^{33–35} Phasing out lead in petrol has proven effective in reducing environmental and population blood lead concentrations.^{36–38} Similarly, approaches including engineering, educational, and law enforcement interventions have reduced the incidence and consequences of injury.³⁹ However, we should point out that exposure to inadequate water and sanitation and to household smoke from solid fuels is likely to characterise vulnerable groups of the population within each country. Therefore, interventions aimed at the improvement of water supply, basic sanitation, and cleaner fuels should be directed towards specific population groups, such as the populations of rural areas and low-income households. Lead exposure and its consequences, as well as most types of injuries and accidents, are also more common in disadvantaged groups, as a result of various factors including the association of poverty with substandard and more hazardous housing, malnourishment, physical stress, and greater exposure to road traffic.^{40,41} Nevertheless, prevention of injuries and of lead exposure should be addressed to the whole population, with emphasis on high-risk groups. Policies to support lead-free petrol, which have been successfully implemented in many European countries,^{28,36} should be accompanied by measures targeting high-risk populations such as those exposed to lead from house paints and lead pipes in old water-supply systems.⁴² Also, the complex nature of the environmental exposure clearly indicates that interventions to reduce the EBD must be multisectoral. Interventions aimed at ensuring use of clean fuels and universal access to improved water and sanitation, clean air, and safer buildings and transport require the involvement of the environment and health sectors and also action in sectors such as transport, energy, urban planning, and education.^{3,8} Whereas the health and environment sectors are responsible for disseminating information, building awareness, training professionals, and promoting healthier behaviours, governments as a whole need to provide the legislative, financial, and policy basis for environmental protection.

Contributors

F Valent participated in the design of the study, data collection, analysis and interpretation of results, and writing of the report. D Little participated in data collection, analysis and interpretation of results, and writing of the report. R Bertollini conceived the idea of the study and collaborated in critical revision of the report. L E Nemer collaborated in the collection of the evidence and in the revision of the report. F Barbone participated in the analysis and interpretation of results and writing of the report. G Tamburlini conceived the idea of the study and collaborated in the design of the study, interpretation of results, and writing of the report.

Conflict of interest statement

None declared.

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