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ORIGINAL RESEARCH

Global and regional burden of chronic respiratory disease in 2016 arising from non-infectious airborne occupational exposures: a systematic analysis for the Global Burden of Disease Study 2016

GBD 2016 Occupational Chronic Respiratory Risk Factors Collaborators

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ABSTRACT

Objectives This paper presents detailed analysis of the global and regional burden of chronic respiratory disease arising from occupational airborne exposures, as estimated in the Global Burden of Disease 2016 study.

Methods The burden of chronic obstructive pulmonary disease (COPD) due to occupational exposure to particulate matter, gases and fumes, and secondhand smoke, and the burden of asthma resulting from occupational exposure to asthmagens, was estimated using the population attributable fraction (PAF), calculated using exposure prevalence and relative risks from the literature. PAFs were applied to the number of deaths and disability-adjusted life years (DALYs) for COPD and asthma. Pneumoconioses were estimated directly from cause of death data. Age-standardised rates were based only on persons aged 15 years and above.

Results The estimated PAFs (based on DALYs) were 17% (95% uncertainty interval (UI) 14%–20%) for COPD and 10% (95% UI 9%–11%) for asthma. There were estimated to be 519 000 (95% UI 441,000–609,000) deaths from chronic respiratory disease in 2016 due to occupational airborne risk factors (COPD: 460,100 [95% UI 382,000–551,000]; asthma: 37,600 [95% UI 28,400–47,900]; pneumoconioses: 21,500 [95% UI 17,900–25,400]). The equivalent overall burden estimate was 13.6 million (95% UI 11.9–15.5 million); DALYs (COPD: 10.7 [95% UI 9.0–12.5] million; asthma: 2.3 [95% UI 1.9–2.9] million; pneumoconioses: 0.58 [95% UI 0.46–0.67] million). Rates were highest in males; older persons and mainly in Oceania, Asia and sub-Saharan Africa; and decreased from 1990 to 2016.

Conclusions Workplace exposures resulting in COPD, asthma and pneumoconiosis continue to be important contributors to the burden of disease in all regions of the world. This should be reducible through improved prevention and control of relevant exposures.

INTRODUCTION

Airborne respiratory hazards (inorganic and organic particulate matter, vapours, gases and fumes) are a common exposure in occupational settings and many studies have identified resulting malignant and chronic respiratory disease as an important component of the occupational injury and disease burden at both country and global levels.^{1–10} Work-related respiratory diseases remain a problem even

Key messages**What is already known about this subject?**

- Occupational respiratory exposures have been shown to be an important cause of chronic work-related respiratory disease at national and global level.
- The last analysis of this issue at the global level was for the year 2000—this paper provides a new analysis for 2016.

What are the new findings?

- Analysis of the Global Burden of Disease data set suggests that globally there were about 519,100 deaths and 13.6 million disability-adjusted life years in 2016 from chronic respiratory disease due to occupational airborne exposures.
- The population attributable fraction for chronic obstructive pulmonary disease (COPD) was 17% and for asthma was 10%.
- Workplace exposures resulting in COPD, asthma and pneumoconioses remain important contributors to the burden of disease in all regions of the world.

How might this impact on policy or clinical practice in the foreseeable future?

- These findings highlight opportunities to continue to reduce chronic respiratory disease burden worldwide by improving prevention and control of workplace airborne exposures.

in high-income countries, as shown by incident cases of pneumoconioses that are still occurring.^{11 12}

The Global Burden of Disease (GBD) Comparative Risk Assessment (CRA) project was the first to consider the burden of occupational chronic respiratory disease comprehensively at a regional and global level, estimating the burden for the year 2000.¹³ That study included airborne exposures leading to asthma, chronic obstructive pulmonary disease (COPD), asbestosis, coal workers' pneumoconiosis (CWP) and silicosis.¹⁴

The new GBD initiative, conducted by the Institute of Health Metrics and Evaluation, first focused on 2010¹⁵ and has been updated several times since.^{16–19} It provides a detailed analysis of the



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burden of disease and injury overall and arising from specific risk factors. One set of those risk factors comprises occupational exposures,¹⁸ but no detailed analysis of the occupational risk factor results has been undertaken.

This paper presents a detailed analysis of the global and regional burden of chronic respiratory disease arising from non-infectious occupational airborne exposures, as estimated in the GBD 2016 study. Malignant occupational respiratory disease²⁰ and an overview of all occupational risk factors²¹ are considered in companion papers.²⁰

METHODS

General approach

The general methodology used in GBD 2016 is described elsewhere,¹⁸ as is the overall approach to occupational risk factors.²¹ These methods are briefly summarised here. A more detailed description is provided here of the analyses of occupational exposures to particulate matter, gases and fumes (PMGF), secondhand smoke (SHS), asthmagens and pneumoconiotic dusts and their associated outcomes.

The burden of occupational respiratory disease for PMGF and SHS (causing COPD) and for asthmagens was estimated using the population attributable fraction (PAF), that is, the proportion of deaths or disability-adjusted life years (DALYs) that would not have occurred if exposure was at the theoretical minimum risk exposure level; this was then used to estimate attributable numbers of deaths or DALYs. The PAF requires information on the relative risk of the disease due to the exposure of interest and the proportion of the target population exposed. Pneumoconioses were estimated directly as part of the overall GBD estimates of prevalence and deaths for each included cause. Age-standardised rates (per 100 000 people) were based only on persons aged 15 and above. Results were calculated for all years from 1990 to 2016, inclusive; the 2016 findings are the focus of this paper. The socio-demographic index (SDI) is a composite indicator of development status based on total fertility rate, mean education for those aged 15 and older and lag distributed income per capita.¹⁸ Region-specific, SDI-specific and global results are reported here. Country-specific information is available through the GBD Compare data visualisation.²² High-income countries were defined as countries in the Australasia, high-income North America, Western Europe and Asia Pacific regions, and low/middle-income (LMI) countries as all other countries. Employment data came from the International Labour Organization Labour Force,²³ supplemented where necessary by sub-national data sources and modelling. PAFs for all carcinogens except asbestos were estimated for each age-sex-country group using the equation based on Levin²⁴:

$$PAF = \frac{\sum_{x=1}^n RR(x)P(x) - 1}{\sum_{x=1}^n RR(x)P(x)}$$

where P(x) is the proportion of persons exposed at level x in the relevant population and RR(x) is the relative risk corresponding to exposure level x.

PMGF and SHS

Industry was used as a proxy for exposure to PMGF because we identified no suitable and valid data sources at a country or global level of exposure to PMGF, either singly or to PMGF as a group. Current industry was used as the basis of exposure estimates, but the estimates of proportions exposed (ie, workers who experienced more than trivial exposure) within

each industry (nine categories—see online supplementary table S1) were designed to take into account past exposure (to estimate ever exposed), given that both past and current exposure appear to increase the risk of COPD. Estimates of proportion exposed at lower and higher levels in high income and LMI countries were based on sparse published data (see online supplementary material) and expert opinion by GBD collaborators (online supplementary table S1). Information on risk was obtained by conducting a systematic review of international literature and meta-analysis (unpublished) of relevant results.^{5,25} Relative risks in these studies were for COPD greater than or equal to Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage II: defined as requiring non-reversibility after using bronchodilators for provocation, a forced expiratory volume in one second/forced vital capacity (FEV₁/FVC) ratio of less than 0.70 and an FEV₁ of less than 80% predicted.²⁶ Relative risk estimates were used for an overall 'lower' level (RR=1.44; 95% CI 1.07–1.95) and an overall 'higher' level (RR=2.31; 95% CI 1.45 to 3.73) of exposure to the agents of concern ('higher' and 'lower' were based on the exposure descriptions in the papers).^{5,25} The reference group was persons not working and persons working in trade, finance or service industries. The prevalence of exposure to PMGF was determined using the following equation:

$$1) \text{ Prevalence of Exposure}_{c,y,s,a,l} = \sum_{EA} \text{Proportion}_{EA,y} * EAP_{c,y,s} \\ * \text{Exposure level proportion}_{EA}$$

where EAP = economically active population, c = country, s = sex, EA = economic activity, l = level of exposure, y = year and a = age.

Exposure information on SHS was based on the CAREX (Carcinogen Exposure) database, which provides industry-specific information from 1990 to 1993 on the prevalence of exposure to various carcinogens in countries of Western Europe,²⁷ as described elsewhere.²⁰ The relevant relative risks were those used for SHS in the general GBD 2016 analysis.¹⁸

Asthmagens

Exposure and relative risks for asthmagens were based on the current occupation distribution (eight categories—see online supplementary table S2) because there were no suitable and valid data sources at a country or global level describing exposure to the wide range of occupational asthmagens. All relative risk information, except that for agricultural occupations, came from a study by Karjalainen and coworkers, a comprehensive national population study of incident asthma.^{7,8} Relative risks for agricultural occupations were based on a study by Kogevinas and coworkers,²⁸ using a weighted average of the separate estimates for 'farmers' and 'agricultural' workers provided in the paper. This information was used because the results were thought to be more generalisable to agriculture in the rest of the world, especially for LMI regions. Separate risks were available and used for males and females (except for agricultural operations), although the sex-specific risks were similar and within the limits of random variation. The same relative risks were used for all age groups. The counterfactual was persons not working and administrative workers. Byssinosis was included as asthma for the purposes of the analysis. The prevalence of exposure to asthmagens was determined using the following equation:

$$2) \text{ Prevalence of Exposure}_{c,y,s,a} = \sum_{EA} \text{Proportion}_{OCC,y} * EAP_{c,y,s}$$

where EAP = economically active population, c = country, s = sex, OCC = occupation, y = year and a = age.

Pneumoconiotic dusts

As mentioned, pneumoconioses were estimated directly as part of the overall GBD estimates of prevalence and deaths for each included cause, rather than using the attributable fraction approach. The methods used are described elsewhere.²⁹ The attributable fraction is essentially 100% because virtually all pneumoconioses arise as a result of occupational exposure. Separate estimates were available for silicosis, asbestosis and CWP, with the remaining cases grouped under an ‘other pneumoconiosis’ category.²³

Statistical approach

The main modelling and analyses employed to produce the GBD 2016 data, and the calculation and use of 95% uncertainty intervals (95% UI), were as described elsewhere.^{18 21} Uncertainty intervals are primarily presented in detail in the tables to assist with the flow of the text.

RESULTS

There were estimated to be about 519 000 (95% UI 441 000–609 000) deaths from chronic respiratory disease in 2016 due to occupational airborne risk factors. The vast majority (460 000 [95% UI 382 000–551 000]; 89%) of these were due to COPD arising from PMGF and SHS. The remaining deaths were from asthma (37 600 [95% UI 28 400–47 900]; 7%), due to exposure to a range of asthmagens, and from pneumoconiosis (21 500 [95% UI 17 900–25 400]; 4%), arising from exposure to pneumoconiotic dusts. Males accounted for 75% (390 000) of the deaths overall and between 69% (asthmagens) and 88% (pneumoconiotic dusts) for individual risk factors. The relative contribution of the different risk factors was similar when the burden was measured in terms of DALYs (13.6 [95% UI 11.9–15.5]million DALYs overall; COPD: 10.7 [95% UI 9.0–12.5]million; asthma: 2.3 [95% UI 1.9–2.9] million; pneumoconioses: 0.58 [95% UI 0.49–0.67]million), with 79% of the DALYs due to PMGF and SHS. Males accounted for 73% (9.9 million) of the DALYs (table 1).

PMGF and SHS

The PAF for COPD arising from occupational exposures was 17% (95% UI 14%–20%) for DALYs (16% for deaths), ranging from a low of 10% in Central sub-Saharan Africa to 21% in East Asia (table 2). The PAF was much higher in males (21%) than females (11%) and peaked at about 24% in 60–64-year-old males. The highest number of deaths and the highest rate of deaths from COPD due to occupational exposures occurred in the older age groups, often beyond usual retirement age. Males had three to four times the number and rate of deaths compared with females. The peak for number of DALYs occurred in the 65–74 year age group, but the rate of DALYs increased considerably with age and was highest in the 75–84 year group for both males and females (online supplementary figures S1-S4).

By far the highest number of deaths and DALYs from COPD occurred in East Asia and South Asia, the regions with the largest populations, which together accounted for about 71% of both measures. The highest rates of deaths were in Oceania, South Asia and East Asia, the rates in these three regions being considerably higher than elsewhere (the lowest rates were in high-income Asia Pacific and Eastern Europe).

The same regions had the highest DALY rates (the lowest DALY rates were in Andean Latin America, high-income Asia Pacific and the Caribbean). Rates tended to be higher in low-middle and middle SDI regions, and there was considerable variation between regions.

Table 1 Global occupational-attributable deaths, DALYs and PAFs from chronic respiratory disease due to airborne exposures by risk factor and sex, 2016 (number, percent and proportion [95% uncertainty interval])*

| Risk factor | Deaths | | | DALYs | | | PAFst | | | |
|----------------------|------------------------------|------------------------------|------------------------------|---------------------------------------|------------------------------------|-------------------------------------|-------|---------------------|--------------------|---------------------|
| | Total | Females | Males† | Total | Females | Males | %‡ | Males | Females | Total |
| Asthmagens | 26 103 (17 900–35 300) | 11 471 (8 700–15 200) | 37 574 (28 400–47 900) | 2 339 480 (1 860 900–2 923 300) | 871 133 (666 100–1 109 600) | 1 468 347 (1 141 200–1 874 300) | 17.2 | 13.0 (12.0–14.0) | 7.1 (6.3–8.0) | 9.9 (9.0–11.0) |
| PMGF+SHS** | 343 122 (270 900–422 000) | 116 958 (87 100–153 300) | 460 080 (381 500–551 300) | 10 687 953 (9 019 900–12 517 000) | 2 717 967 (2 143 400–3 328 600) | 7 969 986 (6 518 000–9 469 200) | 78.6 | 21.0 (18.0–25.0) | 11.0 (9.0–13.0) | 17.0 (14.0–20.0) |
| Pneumoconiotic dusts | 18 997 (15 500–22 700) | 2 491 (2 100–3 200) | 21 488 (17 900–25 400) | 576 977 (493 600–673 500) | 58 060 (49 400–70 700) | 518 917 (439 900–611 300) | 4.2 | 100 | 100 | 100 |
| Total | 388 222 (313 900–466 600) | 130 920 (100 500–167 700) | 519 142 (441 000–608 900) | 13 604 438 (11 912 000–15 502 800) | 3 647 170 (3 010 800–4 335 200) | 9 957 269 (8 520 200–11 450 300) | 100.0 | 19.0 (16.0–22.0) | 9.0 (7.0–11.0) | 15.0 (13.0–17.0) |

*DALYs=disability-adjusted life years; PAF=population attributable fraction.

†PAFs (%) based on DALYs.

‡The numbers in brackets in the whole table are 95% uncertainty intervals.

§Percentage of chronic respiratory disease deaths due to occupational risk factors that were due to this risk factor.

¶Percentage of chronic respiratory disease DALYs due to occupational risk factors that were due to this risk factor.

**Particulate matter, gases and fumes (PMGF) and secondhand smoke (SHS) causing chronic obstructive pulmonary disease.

Table 2 Deaths, YLLs, YLDs, DALYs and PAFs from COPD due to occupational exposure to PMGF and SHS, by region, 2016 (number, percent, rate, proportion)*

| Region | Deaths number | Deaths % | YLLs number | YLDs number | DALYs number | DALYs % | Deaths rate† | YLLs rate† | YLDs rate† | DALYs rate† | YLL %‡ | YLD %‡ | PAF (deaths)§ | PAF (DALYs)¶ |
|------------------------------|------------------|-------------|----------------|----------------|-----------------|------------|-----------------|---------------|---------------|----------------|-----------|-----------|------------------|-----------------|
| High-income North America | 16 669 | 3.6 | 287 084 | 154 716 | 441 800 | 4.1 | 9.8 | 173 | 95 | 267 | 65.0 | 35.0 | 9.4 | 11.9 |
| Australasia | 1047 | 0.2 | 15 975 | 4922 | 20 897 | 0.2 | 7.7 | 122 | 39 | 161 | 76.4 | 23.6 | 10.0 | 13.1 |
| High-income Asia Pacific | 5150 | 1.1 | 61 981 | 70 847 | 132 828 | 1.2 | 4.8 | 61 | 76 | 136 | 46.7 | 53.3 | 12.0 | 15.5 |
| Western Europe | 18 258 | 4.0 | 250 656 | 73 485 | 324 141 | 3.0 | 7.8 | 113 | 35 | 148 | 77.3 | 22.7 | 9.1 | 11.6 |
| Southern Latin America | 2844 | 0.6 | 44 526 | 4967 | 49 493 | 0.5 | 10.8 | 174 | 20 | 194 | 90.0 | 10.0 | 12.2 | 14.3 |
| Eastern Europe | 6391 | 1.4 | 119 566 | 21 018 | 140 584 | 1.3 | 6.3 | 119 | 21 | 140 | 85.0 | 15.0 | 12.7 | 13.6 |
| Central Europe | 4622 | 1.0 | 78 183 | 20 299 | 98 482 | 0.9 | 7.9 | 136 | 36 | 172 | 79.4 | 20.6 | 12.2 | 13.9 |
| Central Asia | 2584 | 0.6 | 51 612 | 8277 | 59 889 | 0.6 | 10.1 | 190 | 29 | 219 | 86.2 | 13.8 | 16.4 | 16.8 |
| Central Latin America | 7042 | 1.5 | 107 850 | 25 554 | 133 404 | 1.2 | 9.3 | 139 | 31 | 171 | 80.8 | 19.2 | 13.6 | 15.1 |
| Andean Latin America | 1241 | 0.3 | 17 903 | 4217 | 22 120 | 0.2 | 7.1 | 99 | 23 | 122 | 80.9 | 19.1 | 15.3 | 16.1 |
| Caribbean | 1191 | 0.3 | 20 636 | 3576 | 24 213 | 0.2 | 7.2 | 126 | 22 | 147 | 85.2 | 14.8 | 13.2 | 14.2 |
| Tropical Latin America | 9936 | 2.2 | 179 699 | 25 150 | 204 849 | 1.9 | 13.7 | 239 | 32 | 271 | 87.7 | 12.3 | 15.1 | 17.3 |
| East Asia | 171 300 | 37.2 | 2 634 163 | 592 605 | 3 226 768 | 30.2 | 31.5 | 461 | 99 | 560 | 81.6 | 18.4 | 18.8 | 20.5 |
| Southeast Asia | 28 029 | 6.1 | 508 878 | 350 306 | 859 183 | 8.0 | 15.0 | 252 | 164 | 415 | 59.2 | 40.8 | 18.3 | 18.7 |
| Oceania | 886 | 0.2 | 21 518 | 3182 | 24 700 | 0.2 | 35.9 | 767 | 107 | 874 | 87.1 | 12.9 | 13.9 | 13.1 |
| North Africa and Middle East | 9834 | 2.1 | 193 777 | 69 764 | 263 541 | 2.5 | 6.9 | 125 | 42 | 167 | 73.5 | 26.5 | 12.4 | 12.8 |
| South Asia | 157 117 | 34.1 | 3 049 410 | 1 176 092 | 4 225 502 | 39.5 | 34.8 | 626 | 227 | 853 | 72.2 | 27.8 | 15.9 | 16.5 |
| Southern sub-Saharan Africa | 2117 | 0.5 | 39 719 | 15 450 | 55 169 | 0.5 | 11.2 | 197 | 72 | 269 | 72.0 | 28.0 | 12.7 | 12.3 |
| Western sub-Saharan Africa | 4775 | 1.0 | 105 149 | 39 099 | 144 248 | 1.3 | 7.9 | 144 | 49 | 192 | 72.9 | 27.1 | 16.2 | 15.6 |
| Eastern sub-Saharan Africa | 7716 | 1.7 | 154 524 | 46 238 | 200 761 | 1.9 | 12.3 | 217 | 60 | 277 | 77.0 | 23.0 | 19.4 | 18.3 |
| Central sub-Saharan Africa | 1333 | 0.3 | 27 051 | 8328 | 35 379 | 0.3 | 7.3 | 130 | 36 | 166 | 76.5 | 23.5 | 9.8 | 9.5 |
| High SDI | 41 455 | 9.0 | 630 080 | 319 949 | 950 029 | 8.9 | 7.7 | 122 | 65 | 187 | 66.3 | 33.7 | 9.8 | 12.4 |
| High-middle SDI | 55 985 | 12.2 | 855 050 | 280 400 | 1 135 450 | 10.6 | 12.6 | 191 | 63 | 253 | 75.3 | 24.7 | 15.7 | 17.4 |
| Middle SDI | 185 785 | 40.4 | 3 067 814 | 1 016 253 | 4 084 066 | 38.2 | 24.0 | 377 | 110 | 486 | 75.1 | 24.9 | 17.9 | 19.3 |
| Low-middle SDI | 156 339 | 34.0 | 2 995 849 | 971 878 | 3 967 727 | 37.1 | 29.5 | 522 | 169 | 691 | 75.5 | 24.5 | 15.9 | 16.2 |
| Low SDI | 20 517 | 4.5 | 421 068 | 129 612 | 550 681 | 5.2 | 16.2 | 291 | 83 | 374 | 76.5 | 23.5 | 15.2 | 14.9 |
| Global | 460 080 | 100.0 | 7 969 861 | 2 718 092 | 10 687 953 | 100.0 | 18.1 | 309 | 103 | 412 | 74.6 | 25.4 | 15.7 | 16.8 |

*YLL=years of life lost; YLD=years of life lived with disability; DALYs=disability-adjusted life years; PAF=population attributable fraction; COPD=chronic obstructive pulmonary disease;

PMGF=particulate matter, gases and fumes; SHS=secondhand smoke.

†Per 100 000 persons.

‡Percentage of DALYs.

§Percentage of all COPD deaths due to occupational exposures.

¶Percentage of all COPD DALYs due to occupational exposures.

SDI, socio-demographic index.

Seventy-five percent of the DALYs were due to years of life lost (YLLs); this predominance of YLLs was seen in nearly all regions (table 2). Information on the separate contribution of SHS to COPD is presented in the online supplementary material.

Asthmagens

The PAF for asthma from occupational exposures was estimated to be 9.9% (95% UI 9.0%–10.9%) based on DALYs (8.9% [95% UI 7.8–10.1%] based on deaths), ranging from 4.1% in Central sub-Saharan Africa to 12.0% in South Asia (table 3). The PAF was higher for males (13%) than females (7%) and peaked at around 18% between the ages of about 35 and 49 years.

Deaths arising from occupational exposure to asthmagens occurred at all ages from 15 to 79 years, but the highest numbers occurred in persons aged 55–64 and the highest rates in persons aged 65–79. The burden was spread more evenly across age groups in terms of DALYs, with the highest number of DALYs in the 45–54 year age group and the highest rates in the 55–64 year age group (online supplementary figures S5–S8).

The highest number of deaths occurred in South Asia and Southeast Asia, and rates were highest in the low and low-middle SDI regions, particularly Oceania, South Asia and Southeast Asia (the lowest rates were in Western Europe and Central Europe). A similar pattern was seen for DALYs (the lowest rates were in

East Asia and Tropical Latin America). Overall, YLLs and years of life with disability each contributed about 50% to the DALYs. However, low and low-middle SDI regions had a much higher proportion of DALYs due to YLLs compared with high-income regions, reflecting that a higher proportion of deaths occurred at younger ages in these regions compared with the high and high-middle SDI regions (table 3).

PNEUMOCONIOTIC DUSTS

The PAF for all pneumoconioses was assumed to be 100%. Silicosis (48%) was the largest specific cause of death from pneumoconiosis, ahead of asbestosis (16%) and CWP (12%), but about one-quarter of the deaths were classified in the ‘other pneumoconiosis’ category. There was a similar distribution between pneumoconiosis categories in terms of DALYs (table 4). The number of deaths increased with age until age 85 years and over, and the age-standardised death rates were highest in the older age groups. There was a broader distribution of DALYs across age groups, and although the rates still increased with increasing age, the rate was highest in the 75–84 year age group (online supplementary figures S9–S12).

The highest number of deaths and DALYs overall and for silicosis and CWP occurred in East Asia, South Asia and Western Europe, with high-income North America replacing East Asia for

Table 3 Deaths, YLLs, YLDs, DALYs and PAFs from asthma due to occupational exposure to asthmagens, by region, 2016 (number, percent, rate, proportion)*

| Region | Deaths | | YLLs number | YLDs number | DALYs | | Deaths rate† | YLLs rate† | YLDs rate† | DALYs rate† | YLL %‡ | YLD %‡ | PAF (deaths)§ | PAF (DALYs)¶ |
|------------------------------|--------|-------|----------------|----------------|-----------|--------|-----------------|---------------|---------------|----------------|-----------|-----------|------------------|-----------------|
| | number | % | | | number | number | | | | | | | | |
| High-income North America | 388 | 1.0 | 15 269 | 71 605 | 86 873 | 3.7 | 0.3 | 10.6 | 50.2 | 60.7 | 17.6 | 82.4 | 8.8 | 10.7 |
| Australasia | 23 | 0.1 | 857 | 11 291 | 12 148 | 0.5 | 0.2 | 7.4 | 100.1 | 107.5 | 7.1 | 92.9 | 4.3 | 9.0 |
| High-income Asia Pacific | 135 | 0.4 | 3493 | 34 431 | 37 923 | 1.6 | 0.2 | 4.2 | 46.3 | 50.5 | 9.2 | 90.8 | 2.6 | 8.0 |
| Western Europe | 182 | 0.5 | 6525 | 94 309 | 100 834 | 4.3 | 0.1 | 3.6 | 55.8 | 59.4 | 6.5 | 93.5 | 2.8 | 8.4 |
| Southern Latin America | 46 | 0.1 | 1558 | 12 849 | 14 407 | 0.6 | 0.2 | 6.2 | 51.6 | 57.8 | 10.8 | 89.2 | 4.9 | 7.5 |
| Eastern Europe | 204 | 0.5 | 6750 | 34 060 | 40 810 | 1.7 | 0.2 | 7.2 | 38.1 | 45.2 | 16.5 | 83.5 | 5.2 | 8.2 |
| Central Europe | 59 | 0.2 | 1877 | 16 773 | 18 650 | 0.8 | 0.1 | 3.6 | 34.7 | 38.3 | 10.1 | 89.9 | 3.4 | 8.2 |
| Central Asia | 166 | 0.4 | 5423 | 13 953 | 19 376 | 0.8 | 0.6 | 17.5 | 42.9 | 60.4 | 28.0 | 72.0 | 8.0 | 9.4 |
| Central Latin America | 185 | 0.5 | 6315 | 32 529 | 38 844 | 1.7 | 0.2 | 7.0 | 34.3 | 41.4 | 16.3 | 83.7 | 5.7 | 6.8 |
| Andean Latin America | 31 | 0.1 | 952 | 8977 | 9929 | 0.4 | 0.2 | 4.8 | 42.0 | 46.7 | 9.6 | 90.4 | 7.4 | 6.8 |
| Caribbean | 140 | 0.4 | 5049 | 8442 | 13 491 | 0.6 | 0.8 | 29.6 | 49.3 | 78.9 | 37.4 | 62.6 | 7.5 | 6.5 |
| Tropical Latin America | 176 | 0.5 | 6291 | 22 647 | 28 937 | 1.2 | 0.2 | 7.5 | 26.7 | 34.2 | 21.7 | 78.3 | 6.3 | 7.2 |
| East Asia | 1164 | 3.1 | 35 597 | 162 558 | 198 156 | 8.5 | 0.2 | 5.7 | 26.6 | 32.3 | 18.0 | 82.0 | 5.1 | 9.3 |
| Southeast Asia | 7315 | 19.5 | 224 974 | 142 208 | 367 182 | 15.7 | 3.3 | 96.0 | 57.8 | 153.8 | 61.3 | 38.7 | 9.5 | 11.0 |
| Oceania | 292 | 0.8 | 9862 | 2619 | 12 481 | 0.5 | 9.3 | 297.6 | 71.8 | 369.5 | 79.0 | 21.0 | 7.6 | 8.5 |
| North Africa and Middle East | 1344 | 3.6 | 47 971 | 84 044 | 132 015 | 5.6 | 0.7 | 25.3 | 41.3 | 66.6 | 36.3 | 63.7 | 6.0 | 6.7 |
| South Asia | 21 085 | 56.1 | 669 102 | 223 370 | 892 472 | 38.1 | 3.9 | 117.5 | 37.9 | 155.4 | 75.0 | 25.0 | 9.7 | 12.0 |
| Southern sub-Saharan Africa | 474 | 1.3 | 17 146 | 13 274 | 30 420 | 1.3 | 2.0 | 69.4 | 49.5 | 118.9 | 56.4 | 43.6 | 7.7 | 8.0 |
| Western sub-Saharan Africa | 1395 | 3.7 | 50 249 | 51 856 | 102 105 | 4.4 | 1.5 | 50.7 | 45.3 | 96.1 | 49.2 | 50.8 | 10.7 | 8.5 |
| Eastern sub-Saharan Africa | 2452 | 6.5 | 85 585 | 75 354 | 160 939 | 6.9 | 2.9 | 91.8 | 68.2 | 160.0 | 53.2 | 46.8 | 13.2 | 10.7 |
| Central sub-Saharan Africa | 316 | 0.8 | 11 315 | 10 173 | 21 487 | 0.9 | 1.2 | 41.1 | 33.1 | 74.1 | 52.7 | 47.3 | 5.1 | 4.1 |
| High SDI | 776 | 2.1 | 27 685 | 213 996 | 241 681 | 10.3 | 0.2 | 6.5 | 52.1 | 58.6 | 11.5 | 88.5 | 4.6 | 9.2 |
| High-middle SDI | 1320 | 3.5 | 44 449 | 185 336 | 229 785 | 9.8 | 0.3 | 9.1 | 38.1 | 47.2 | 19.3 | 80.7 | 6.2 | 9.1 |
| Middle SDI | 8807 | 23.4 | 277 589 | 316 569 | 594 158 | 25.4 | 1.0 | 30.5 | 34.5 | 65.0 | 46.7 | 53.3 | 8.1 | 9.3 |
| Low-middle SDI | 21 524 | 57.3 | 683 953 | 297 559 | 981 512 | 42.0 | 3.3 | 101.3 | 41.4 | 142.7 | 69.7 | 30.3 | 9.7 | 11.1 |
| Low SDI | 5147 | 13.7 | 178 483 | 113 860 | 292 343 | 12.5 | 2.9 | 94.3 | 52.3 | 146.5 | 61.1 | 38.9 | 9.9 | 8.9 |
| Global | 37 574 | 100.0 | 1 212 160 | 1 127 320 | 2 339 480 | 100.0 | 1.4 | 44.0 | 40.5 | 84.5 | 51.8 | 48.2 | 8.9 | 9.9 |

*YLL=years of life lost; YLD=years of life lived with disability; DALYs=disability-adjusted life years; PAF=population attributable fraction.

†Per 100 000 persons.

‡Percentage of DALYs.

§Percentage of all asthma deaths due to occupational exposures.

¶Percentage of all asthma DALYs due to occupational exposures.

SDI, socio-demographic index.

asbestosis deaths. The age-standardised death rates were highest in high-income Asia Pacific, East Asia and Oceania (the lowest rates were in Southeast Asia and the Caribbean), and the DALY rates highest in East Asia, Oceania and Southern sub-Saharan Africa (the lowest rates were in the Caribbean and Southeast Asia). Sixty-two percent of the silicosis deaths and 36% of the CWP deaths occurred in East Asia, and 27% of the asbestosis deaths occurred in Western Europe, which also had the second-highest rate (behind East Asia) of silicosis deaths. Western Europe, South Asia and East Asia had the highest number of asbestosis deaths, and East Asia, Australasia and Western Europe had the highest rate of asbestosis deaths (table 4—the rate data for individual pneumoconioses are not shown here).

Changes over time

For COPD, there was little change (4% rise) in the number of deaths due to occupational exposure to PMGF and SHS between 1990 and 2016, but the (standardised) rate of death from COPD declined by 41% over this time. For asthmagens, the number of deaths due to occupational exposure increased by 7% and the rate of death declined by 36%. The number of deaths from pneumoconioses changed minimally (1%) over this period, but the rate of death from pneumoconioses declined by 41%. Changes in the numbers and rates of DALYs were similar to those seen for deaths, except for asthma, which had a 27% increase in DALYs

between 1990 and 2016. The PAFs for asthma rose considerably over this time (21% for deaths; 28% for DALYs), but there was little change in the PAFs for COPD (table 5).

DISCUSSION

This analysis of the GBD 2016 study has shown there is a considerable burden of chronic respiratory disease worldwide and in all regions arising from exposure to occupational risk factors. Chronic obstructive pulmonary disease is the primary resulting disease, in terms of both deaths and DALYs, but asthma and pneumoconioses are also important. Rates were much higher in males than females for all these disorders, but important in both. The lower female rates reflect the fact that women are less likely to be employed in tasks that involve the relevant exposures.²³ The results are consistent with those from the overall GBD respiratory analysis.³⁰ The decreases in per capita burden for most measures, and the increase for asthma DALYs, result primarily from changes in the relevant PAFs that, in turn, reflect changes in the occupation and industry distribution, which are the basis of the exposure assessments.

PMGF, SHS and COPD

The global estimate of the PAF for COPD arising from occupational exposure to PMGF and SHS (17% for DALYs; 16% for deaths) is consistent with most published findings for individual countries and overall. These have typically reported PAFs of the order

Table 4 Global occupational-attributable deaths and DALYs from pneumoconioses due to exposure to pneumoconiotic dusts, by region, 2016 (number and rate)*

| Region | Deaths Asb* | Deaths CWP* | Deaths Sil* | Deaths Oth* | Deaths total | % | Death rate† | YLLs %‡ | YLDs‡ | DALYs | DALYs % | DALY rate‡ |
|------------------------------|-------------|-------------|---------------|-------------|---------------|--------------|-------------|-------------|-------------|----------------|--------------|-------------|
| High-income North America | 674 | 283 | 118 | 78 | 1153 | 5.4 | 0.7 | 55.6 | 44.4 | 27 309 | 4.7 | 16.5 |
| Australasia | 87 | 1 | 11 | 6 | 105 | 0.5 | 0.8 | 88.4 | 11.6 | 1444 | 0.3 | 10.8 |
| High-income Asia Pacific | 345 | 279 | 486 | 477 | 1587 | 7.4 | 1.5 | 95.9 | 4.1 | 21 657 | 3.8 | 21.4 |
| Western Europe | 948 | 330 | 1388 | 147 | 2814 | 13.1 | 1.2 | 92.2 | 7.8 | 35 385 | 6.1 | 15.5 |
| Southern Latin America | 30 | 17 | 132 | 18 | 197 | 0.9 | 0.7 | 87.9 | 12.1 | 3236 | 0.6 | 12.5 |
| Eastern Europe | 37 | 29 | 35 | 172 | 272 | 1.3 | 0.3 | 56.5 | 43.5 | 8501 | 1.5 | 8.6 |
| Central Europe | 38 | 75 | 83 | 64 | 260 | 1.2 | 0.4 | 48.3 | 51.7 | 9058 | 1.6 | 16.0 |
| Central Asia | 14 | 3 | 2 | 49 | 68 | 0.3 | 0.3 | 63.9 | 36.1 | 2460 | 0.4 | 8.7 |
| Central Latin America | 38 | 33 | 90 | 75 | 235 | 1.1 | 0.3 | 49.5 | 50.5 | 9294 | 1.6 | 11.4 |
| Andean Latin America | 9 | 7 | 20 | 82 | 117 | 0.5 | 0.7 | 91.3 | 8.7 | 2351 | 0.4 | 12.6 |
| Caribbean | 4 | 2 | 5 | 13 | 24 | 0.1 | 0.1 | 61.9 | 38.1 | 739 | 0.1 | 4.4 |
| Tropical Latin America | 65 | 50 | 235 | 117 | 468 | 2.2 | 0.6 | 85.0 | 15.0 | 12 780 | 2.2 | 16.1 |
| East Asia | 345 | 960 | 6443 | 1080 | 8828 | 41.1 | 1.5 | 66.5 | 33.5 | 303 318 | 52.6 | 49.8 |
| Southeast Asia | 37 | 13 | 39 | 119 | 208 | 1.0 | 0.1 | 24.8 | 75.2 | 16 480 | 2.9 | 7.7 |
| Oceania | 5 | 1 | 7 | 17 | 30 | 0.1 | 1.4 | 86.0 | 14.0 | 816 | 0.1 | 29.6 |
| North Africa and Middle East | 69 | 43 | 93 | 195 | 401 | 1.9 | 0.3 | 62.7 | 37.3 | 13 882 | 2.4 | 8.2 |
| South Asia | 547 | 519 | 1089 | 1953 | 4109 | 19.1 | 0.9 | 90.8 | 9.2 | 92 603 | 16.0 | 18.4 |
| Southern sub-Saharan Africa | 133 | 12 | 51 | 64 | 260 | 1.2 | 1.3 | 92.6 | 7.4 | 6142 | 1.1 | 28.9 |
| Western sub-Saharan Africa | 10 | 3 | 5 | 38 | 57 | 0.3 | 0.1 | 74.8 | 25.2 | 2099 | 0.4 | 2.4 |
| Eastern sub-Saharan Africa | 47 | 19 | 55 | 108 | 229 | 1.1 | 0.4 | 89.6 | 10.4 | 5745 | 1.0 | 7.5 |
| Central sub-Saharan Africa | 12 | 6 | 15 | 33 | 66 | 0.3 | 0.4 | 90.0 | 10.0 | 1680 | 0.3 | 7.5 |
| High SDI | 2015 | 977 | 1855 | 770 | 5617 | 26.1 | 1.0 | 78.2 | 21.8 | 89 690 | 15.5 | 17.3 |
| High-middle SDI | 307 | 324 | 1702 | 569 | 2902 | 13.5 | 0.6 | 59.2 | 40.8 | 90 287 | 15.6 | 18.9 |
| Middle SDI | 598 | 778 | 5277 | 1521 | 8173 | 38.0 | 1.0 | 68.6 | 31.4 | 273 759 | 47.4 | 31.7 |
| Low-middle SDI | 485 | 548 | 1440 | 1781 | 4253 | 19.8 | 0.8 | 83.4 | 16.6 | 109 444 | 19.0 | 18.2 |
| Low SDI | 90 | 57 | 129 | 266 | 542 | 2.5 | 0.4 | 88.6 | 11.4 | 13 797 | 2.4 | 8.8 |
| Global | 3495 | 2685 | 10 402 | 4906 | 21 488 | 100.0 | 0.8 | 71.9 | 28.1 | 576 977 | 100.0 | 21.9 |

*YLL=years of life lost; YLD=years of life lived with disability; DALYs=disability-adjusted life years; PAF=population attributable fraction; Asb'=asbestosis; CWP=coal workers' pneumoconiosis; 'Sil'=silicosis; 'Oth'=other pneumoconiosis.

†Per 100 000 persons.

‡Percentage of DALYs.

SDI, socio-demographic index.

of 10%–15%, although much higher values have been estimated, particularly for non-smokers, typically due to differences in the level or type of exposures of the included subjects or the use of different assumptions.^{110 31–35} In addition, as smoking rates diminish, the PAF for occupational risk factors will increase. In comparison, the GBD 2016 study estimated PAFs for COPD in regard to smoking and SHS of 43% and ambient particulate matter pollution of 27%.²² The CRA study (covering the year 2000) estimated 318 000 deaths and PAFs from occupational exposure of 13% based on DALYs and 12% based on deaths.¹⁴ The Burden of Obstructive Lung Disease (BOLD) study documented a direct relationship between COPD prevalence and number of years worked in dusty jobs.³⁶

Asthmagens and asthma

As with COPD related to occupational exposures, the occupational asthma PAF estimates of 10% for DALYs and 9% for deaths from this study are consistent with most published findings for individual countries, which are of the order of 10%–15%.^{3 7 8 10 28} and comparable to the PAF due to smoking (10% for DALYs; 14% for deaths).²² The CRA study, which was based on the year 2000, estimated a PAF of 11% based on DALYs and 17% based on deaths (and estimated 38 000 deaths),¹⁴ the differences primarily arising from changes in the employment distribution and slight differences in the general methodology.²²

Pneumoconiotic dusts and pneumoconioses

Obtaining reliable global information on pneumoconiosis cases is challenging. This analysis identified silicosis as the predominant pneumoconiosis, with much lower numbers of cases of asbestosis and CWP. The increase in rates with age is consistent with the published literature,³⁷ and the number of deaths is consistent with the publicly available data for many countries, but also differs considerably for some others for which the estimates here are notably different from the numbers reported in the WHO Mortality Database.³⁸ The reason for this is not clear, but presumably is because of the use of different primary data sources and assumptions in the GBD modelling process. It is likely that most of the moderate proportion of pneumoconiosis deaths and DALYs (both 23%) coded in GBD 2016 as due to 'Other pneumoconioses' were actually due to silicosis, asbestosis or CWP, as these have always been identified as the three main pneumoconioses. The different coding is likely to have arisen due to incomplete coding in the source data and the way this was allocated to specific categories.

Methodological considerations and limitations

Most of the methodological issues specific to the three main outcomes of interest have already been considered in the relevant sections of the Discussion. The main general uncertainties have been

Table 5 Change in global occupational-attributable deaths and DALYs from chronic respiratory disease due to occupational exposure to asthmagens, PMGF, SHS and pneumoconiotic dusts between 1990 and 2016, number and per capita (number and percent [95% uncertainty interval])*

| Risk factor | Deaths | | | DALYs | | |
|----------------------|------------------------------|------------------------------|------------------------|---------------------------------------|---------------------------------------|------------------------|
| | 1990† | 2016 | % change | 1990 | 2016 | % change |
| Asthmagens | 35 228 (24 103–48 462) | 37 574 (28 362–47 936) | 6.7 (–19.5 to 36.1) | 1 845 494 (1 406 629–2 327 424) | 2 339 480 (1 860 896–2 923 319) | 26.8 (0.8 to 58.4) |
| PMGF+SHS | 441 702 (367 000–521 000) | 460 080 (381 500–551 300) | 4.2 (–13.6 to 24.8) | 9 825 539 (8 149 400–11 533 600) | 10 687 953 (9 019 900–12 517 000) | 8.8 (–8.2 to 27.4) |
| Pneumoconiotic dusts | 21 209 (16 000–31 400) | 21 488 (17 900–25 400) | 1.3 (–15.6 to 19.8) | 567 941 (442 576–832 555) | 576 977 (493 632–673 528) | 1.6 (–13.1 to 18.6) |
| Total | 498 139 (407 000–600 900) | 519 142 (427 800–624 600) | 4.2 (–14.9 to 25.4) | 12 238 974 (10 667 700–13 881 800) | 13 604 410 (11 912 000–15 502 800) | 11.2 (–2.7 to 26.7) |

| Risk factor | Deaths per 100 000 persons | | | DALYs per 100 000 persons | | |
|----------------------|----------------------------|---------------------|---------------------------|---------------------------|------------------|---------------------------|
| | 1990† | 2016 | % change | 1990 | 2016 | % change |
| Asthmagens | 2.2 (1.5–3.0) | 1.4 (1.0–1.8) | –36.0 (–51.7 to –18.1) | 108 (82–136) | 85 (67–106) | –21.4 (–37.5 to –1.7) |
| PMGF+SHS | 31.0 (26.8–36.5) | 18.2 (15.0–21.9) | –41.3 (–51.7 to –29.4) | 653 (545–768) | 410 (346–482) | –37.1 (–47.1 to –26.1) |
| Pneumoconiotic dusts | 1.43 (1.08–2.10) | 0.84 (0.70–0.99) | –41.3 (–51.0 to –30.8) | 36 (28–53) | 22 (19–26) | –39.7 (–48.5 to –29.7) |
| Total | 34.6 (28.4–41.6) | 20.4 (16.7–24.6) | –40.9 (–51.6 to –28.8) | 796 (655–957) | 517 (431–613) | –35.1 (–45.8 to –23.0) |

| Risk factor | Population attributable fraction (deaths) (%) | | | Population attributable fraction (DALYs) (%) | | |
|-------------|---|---------------------|-------------------------|--|---------------------|------------------------|
| | 1990* | 2016 | % change | 1990 | 2016 | % change |
| Asthmagens | 7.4 (6.1–8.8) | 8.9 (7.8–10.1) | 20.6 (5.4–36.0) | 7.7 (6.8–8.8) | 9.9 (9.0–10.9) | 27.6 (16.0–40.3) |
| PMGF+SHS | 16.3 (13.7–19.1) | 15.7 (13.8–18.6) | –3.6 (–20.0 to 14.0) | 16.4 (14.0–19.0) | 16.9 (14.3–19.7) | 2.5 (–13.0 to 19.8) |

*DALYs=disability-adjusted Life Years; PMGF=particulate matter, gases and fumes; SHS=secondhand smoke.

†The numbers in brackets in the whole table are 95% uncertainty intervals.

considered in detail in the companion overview paper.²¹ Issues of particular relevance to the presented analysis included basing exposure prevalence estimates on industry (for PMGF and SHS) and occupation (for asthmagens); uncertainty in the prevalence and level of exposure to PMGF overall and in different industries; the potential for mismatch between the relative risk estimates used and the exposure circumstances to which they have been applied; not explicitly taking into account the potential effect of differences in smoking habits and environmental exposures between regions and over time; probable heterogeneity in terms of how chronic respiratory conditions are identified, diagnosed and managed worldwide; and not including some potentially relevant risk factors and outcomes such as respiratory infections,³⁹ other occupational causes of fibrosis apart from pneumoconioses and lung disease arising from nanoparticle exposure.⁴⁰ For both COPD and asthma, the extent and effect of any mismatch between the exposure and the relative risk estimate applied in LMI countries are not clear. It would be helpful to have usable information on this from LMI countries, which might allow different risk estimates to be applied in these countries if appropriate. However, currently the necessary data are not available.

Implications and uses of the data

The main finding of this study is that workplace exposures resulting in COPD, asthma and pneumoconioses remain important contributors to the burden of disease in all regions of the world. The relevant exposures are respiratory and it should be possible to minimise all (or most), and in some instances to essentially eliminate them, through appropriate commitment to, and implementation of,

exposure control interventions to decrease the airborne exposure levels of the relevant hazards. However, it must be recognised that there are a range of PMGF implicated as increasing the risk of COPD and hundreds of known occupational asthmagens. Elimination or appropriate control of many of these exposures will take considerable resources and effort and requires continued vigilance. The study does not provide information on the cost or practicality of eliminating or better controlling the relevant exposures, and the results for COPD and pneumoconioses largely reflect past exposures. However, the high burden of COPD cases suggests the relevant exposures should be a priority in the area of occupational airborne exposures resulting in chronic respiratory disease. The findings also have implications for healthcare costs and social protection in older individuals. Finally, further investment in country-level data sources, especially in LMI countries, would help improve the accuracy and usefulness of the estimates generated by the GBD study.

Conclusions

There are many respiratory conditions that can arise directly, or indirectly, from work. The results from this study indicate that non-malignant/non-infectious respiratory diseases arising from occupational exposures are an important cause of death and disability worldwide. Many of these cases should be preventable by adopting better health and safety approaches, particularly through improved engineering and working conditions.

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is available on the data section of the IHME GBD web site (<http://www.healthdata.org/gbd/data>).

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